PINE FORESTS IN ITASCA STATE PARK, MINNESOTA

A REVIEW OF LITERATURE RELEVANT TO RESTORATION OF PINE FORESTS IN ITASCA STATE PARK, MINNESOTA

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THIS REVIEW INCLUDES INFORMATION FROM ALL DOCUMENTS IN ITASCA FORESTS, VOLUMES 1-6, PREPARED BY BEN THOMA

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ITASCA STATE PARK

Pines have been a major part of the natural history of the Itasca region and have been one of the primary attractions in Itasca State Park. However, regeneration of the great pine stands has been virtually nonexistent since the Park was established in 1891. As early as the 1930's, problems with pine regeneration were noted by Willard (1936). Possible contributing factors cited included soil toxicity, depth of duff, lack of light, and foraging by deer and rodents. In the 1950's, Hansen and Brown (1950) and Hansen and Duncan (1954) also documented problems with pine regeneration. Heavy brush, deer browsing and absence of fire were identified as the causes.

Numerous other studies have addressed the problems of pine regeneration at Itasca State Park and have attempted to offer solutions. Among the recommendations were reduction of the deer herd, some form of ground disturbance, such as fire or mechanical scarification to expose the mineral soil, and brush elimination by chemical or mechanical means.

Suppression of fire played a major role in the downfall of pine regeneration in the Park. Without fire to expose the mineral soil, eliminate more shade tolerant understory brush and, in the case of jack pine, to open the serotinous seed cones, succession was allowed to proceed. This has led to the conversion of much of the pine to balsam fir-spruce and northern hardwood stands. By 1930, wildfires within the Park were practically eliminated. Before this time they were common. For example, during the period from 1650-1699, the average interval between fires was 16.7 years, and between 1900-1922, the period of land clearing and logging, the interval between fires had decreased to 3.1 years (Anfang 1972a).

In a survey conducted by McCool (1966) the use of prescribed burning for vegetation management in Itasca State Park was viewed favorably by administrators and scientists because it is a natural process and played an important role in the pre-settlement forest. The use of tree cutting was viewed by some research scientists as acceptable, but only during the initial stages of red and white pine regeneration and not on a continuing basis, because it is not a natural factor of ecological succession. The use of herbicides was generally, but not unanimously, viewed negatively by each group.

Although natural ecological processes may be considered preferable in a management plan for the Park, some of those processes have been removed by man and probably can not be re-established fully in the future. Furthermore, the mere presence of civilization in the area disrupts the ecology of the Park. Therefore, to counteract the negative aspects of man's past and future intervention in the natural environment of the Park, further artificial management techniques may be necessary. As stated by Hansen and Duncan (1954) "Natural succession, or the lack of intervention by man, does not necessarily mean that recreational values will be maintained or improved. In fact, at Itasca, it has been demonstrated that the major vegetational attraction, its pine forests, will largely disappear unless man intervenes to reverse the trend." They recommend far-sighted, intelligent manipulation aimed at providing maximum recreational values in the areas of Itasca State Park zoned for recreational use, which would include re-establishment of the pine stands.

Four basic community types which occurred in the vicinity of the Park were identified by McAndrews (1965). They are the pine/hardwood forest, mesic deciduous forest, oak savanna and prairie. Soil texture, climate and fire frequency were found to be significant limiting factors in determining geographic limits of each type. The pine/hardwood forest predominates in areas where summer temperatures are lower, the growing season is shorter and winter snow cover is greater. Pines occurred chiefly on coarse-textured, till soils. The soils of the Lake Itasca region are extremely variable, "ranging from those composed of very stony and sandy material to heavy clay with few stones. The soil types are arranged in such a complicated manner that small areas of heavy clay soil are often found within sterile sandy plains" (Lee 1924).

Kurmis (1969) found that pine reproduction in Itasca State Park occurs on dry, nutrient-poor sites, spruce-fir reproduction on mesic, nutrient-poor to intermediate nutrient sites and hardwood reproduction on mesic, nutrient-rich sites. The peaks of hardwood and spruce-fir reproduction cover coincide with the distribution pattern of dense tree cover, while the peak of pine reproduction cover on dry, nutrient poor sites is associated with rather open tree cover. Shrub cover peaks on dry to mesic, intermediate nutrient sites and is lowest on mesic, nutrient-poor and mesic nutrient-rich sites.

SUCCESSION

Succession is the process of change in species composition of a plant community over time in response to changes in specific factors. The general pattern of succession involves procession from a post-disturbance pioneer species to a climax species, which will inhabit an area for an indefinite period of time. Reports from early studies in northern Minnesota (Bergman and Stallard 1916, Bergman 1924, Stallard 1929) advanced the view that white and red pine were the climax species. Stallard (1929) identified the critical factors in determining the path of secondary succession to be the decrease in light and increase in available water that result from the occupation of a disturbed site by invading vegetation. In Itasca County, about 80 miles to the east, the climax forest was believed to be dominated by balsam fir and basswood (Grant 1934). This "transition climax" was attributed to competition between the fir-paper birch association and the sugar maple-basswood association. White and red pine were considered an edaphic subclimax on sandy soils.

The importance of fire as an ecological factor was not fully recognized by early scientists investigating forest communities and succession. Beginning in about the 1950s, ecologists (Spurr 1954, Swain 1973, Buell and Niering 1957, Ahlgren and Ahlgren 1960) began to develop an understanding of the importance of fire in secondary succession in northern Minnesota. These workers established the fact that fires were frequent and that they played a significant role in community structure. However, it was the research conducted by Heinselman (1973, 1981) in the Boundary Waters Canoe Area Wilderness and Frissell (1973) in Itasca State Park that established the mechanism by which fire actually originated and maintained the magnificent forests of red and white pine.

The importance of disturbance in the process of succession has received increasing attention in the past few decades. Ohmann et al. (1973) state that the time elapsed since the last major disturbance and the type of vegetation present at the time of that disturbance may be more important than differences in environmental parameters in determining the composition and structure of the present upland plant communities over a relatively small region. According to Oliver (1981), disturbance severity and frequency are important determinants of dominant species in forests. He also asserts that a single group of species is not predestined to inhabit an area, but that several different communities could potentially inhabit an area indefinitely. Oliver further concludes, based upon a summarization of past studies pertaining to large-scale disturbances in North American forests, that recruitment of new stems into a forest occurs during a relatively short period following a disturbance, rather than being a constant occurrence which would result in an all-age forest. He maintains that species that appear prevalent as the forest ages are generally present from the start, but are not obvious at first, often because of their small size and infrequency relative to the early dominants.

In the Lake States, pines have been observed to proceed in the absence of fire from jack pine to red pine to white pine and then finally to northern hardwoods, or to spruce-fir in northeastern Minnesota (Rudolf 1990). A given species may function in a variety of successional roles depending upon the conditions of the site in which it is found. For example, white pine may function as a pioneer, as a physiographic climax species on dry, sandy soils, as a long-lived successional species, or as a component of a climax forest (Wendel and Smith 1990). On wet clay and loam soils, white pine seedlings can survive in openings of fir, spruce and birch stands and can eventually succeed them (Stallard 1929).

Boreal conifers and northern hardwoods form a fragmented border landscape that can arise from stochastic disturbances or positive feedbacks in nutrient, herbivore and fire cycles that cause divergent patterns of succession starting from initially similar conditions (Pastor and Mladenoff 1991). Maycock and Curtis (1960) assert that succession to boreal conifers or northern hardwoods depends primarily on site conditions and microclimate. Within a given region, boreal or northern hardwood stands segregate along environmental gradients, particularly moisture, in a way that obscures more global patterns. Where the climate is warm enough to support northern hardwoods, boreal stands are confined to wet or cool microclimates. Pastor and Mladenoff(1991) do agree that, within a given stand, site conditions and microclimate take on great importance in determining the balance of boreal versus northern hardwood species.

In northern hardwood stands, disturbance does not necessarily set the succession process back. In the absence of fire, northern hardwoods that are logged or blown down regenerate primarily from sprouts or saplings. An initial stage of pioneer species, such as aspen or birch, does not have to occur (Pastor and Mladenoff1991).

Due to the complex interactions between climate cycles, soil types, fuel decomposition and flammability, topography, animal populations, reproductive strategies and disturbance intervals, it has been suggested that there is no succession in boreal forests in the linear sense as it is applied in more temperate regions. "The mosaic of forest types simply cycles among combinations of different species depending on whether factors that promote change occur synchronously and, therefore, amplify each other, or whether they occur out of phase and thereby dampen each other" (Pastor and Mladenoff1991).

SUCCESSION IN ITASCA STATE PARK

Within Itasca State Park, there exists a transitional belt between coniferous and hardwood forests. The edaphic element (soil composition/soil moisture) combined with evaporative power of air, species tolerance to shade and relative light intensity within each forest type are the major influences of succession in this region according to Lee (1924). Climatic factors were found to have very little bearing on local successions. Frequency of seed production may also be a factor in determining forest succession because most pines bear seed with definite periodicity, whereas hardwoods, fir and spruce bear seed almost every year.

The general pattern of succession in Itasca State Park ranges from a post-disturbance pioneer species, such as aspen or jack pine, to an intermediate stage of red and/or white pines, to the climax stage of the shade tolerant maple-basswood or spruce-fir forest types. Kell (1938) found a number of patterns in Itasca State Park in the succession from jack pine to maple-basswood or fir-spruce. For example, pure white pine never followed jack pine, red pine replaced jack pine on soils ranging from very coarse to intermediate in texture, and sugar maple-basswood forests more commonly succeeded white pine stands than red or red/white pine mixed forests. In some pine stands there was no evidence of succession towards maple-basswood or fir-spruce even though these stands showed no significant difference in moisture equivalents from other pine stands where climax activity was evident. This finding led to the conclusion that some factor(s) other than moisture holding capacity of the soil seem(s) to be responsible for the climax resistance of some pine stands.

PIONEER SPECIES

Aspen and jack pine are post-fire pioneer species found in Itasca State Park. Both species are adapted to regenerate after fire, jack pine by seed from serotinous cones, and aspen from suckers. Neither species is shade tolerant or long-lived, so they are usually replaced by other species in the absence of disturbance.

Hansen and Kurmis (1972) found the following patterns of succession in aspen stands in north central Minnesota. Succession in pure aspen stands may develop from aspen suckers if the stand is subject to drastic blowdown. In most instances, however, more gradual deterioration will occur and brush, especially beaked hazel, will increase. If red pine, jack pine or paper birch are present, they will replace aspen because they have longer life spans. Aspen stands with oaks will probably develop into oak forest with a dense shrub understory. Aspen stands on moist, rich soils will succeed to sugar maple, basswood, ironwood and red maple. The shrub layer in these stands will be sparse or absent and will consist of leatherwood, alternate-leaved dogwood and other species.

Jack pine is a pioneer, temporary type on nearly all sites in the north central states except dry, sandy soils. Successional forces generally increase as site quality increases adding to the difficulty of maintaining jack pine on better sites (Benzie 1977b). In loamy sands and sandy loams in northern Minnesota, the usual succession is from jack pine to red pine to hardwoods composed of sugar maple, basswood and red oak. Frequently, the red and white pine stages are absent and jack pine is followed by speckled alder, American hazel, beaked hazel, paper birch and aspen. This stage is followed by either sugar maple-basswood or spruce-fir (Rudolph and Laidly 1990).

Jack pine stands on deep, dry, sandy soils such as Grayling, Rubicon, Plainfield, Vilas and Menagha are not easily invaded by other tree species. Therefore, successional changes are so slow on these soils that jack pine is able to establish an edaphic climax (Lee 1924, Benzie 1977b).

INTERMEDIATE SPECIES

Red and white pine are more shade tolerant than jack pine, so they can invade stands of jack pine if a seed source is available. They are long-lived species, surviving for several centuries, so they can outlive and succeed jack pine in mixed stands. However, red and white pines are not as shade tolerant as hardwoods which are capable of invading pine stands and surviving in the understory. In the absence of disturbance, red and white pine seedlings have difficulty becoming established under the shade of the parent trees and dense undergrowth. Therefore, red and white pine are not considered to be climax species, but intermediate in the succession stages.

A 26-year analysis of a white pine-sugar maple forest in Itasca State Park by Peet (1984) revealed that succession was taking place in the understory below the pines wherein aspen and birch were being replaced by ironwood, basswood and maple. The observed succession seemed to be one initiated by cessation of the ground fires of the late 19th century which had kept the stands of fire-resistant pine open and comparatively free of hardwood growth. The most likely scenario for the future of this stand was that the existing advanced regeneration of maple, basswood and oak, which survives the demise of the pines, will rapidly assume canopy dominance. The extent to which shade intolerant species invade will depend on the degree to which the existing understory is damaged, the synchrony of mortality of the pines, and the population density of deer.

Succession has been observed to be retarded in Itasca State Park on stands of red pine on southerly and southwesterly slopes with adjacent open areas below (Blowers 1960). This could be due to drier conditions resulting from earlier warming and loss of snow cover in spring, increased runoff due to slope, and prevailing southwesterly summer winds. However, these sites do not support pine regeneration, so they could not be defined as edaphic climaxes capable of reproducing themselves.

CLIMAX SPECIES

Climax species are characterized as those that are able to invade and remain dominant in a stand indefinitely in the absence of disturbance. This requires shade tolerance and the ability to reproduce under the parent trees on undisturbed soil. Spruce-fir and maple-basswood are two climax types that are found in Itasca State Park. Bakuzis (unk.) found that on mesic, nutrient-poor sites, balsam fir is able to prevent shrub invasion. But, after windthrow uproots the balsam fir trees and disturbs the soil, pine reproduction may occur.

Peet (1984) documented the succession of a white pine stand towards maple-basswood over a 26-year period in Itasca State Park. Due to the lack of disturbance by fire since the early 1900's, maple-basswood had moved into the understory. Although the white pine canopy was stable and was expected to remain intact for many more years, it appeared that the maple-basswood understory would become dominant as the pines died out and would prevent the establishment of shade intolerant species.

In a red pine stand in Itasca State Park, Henry (1968) documented vegetation changes over a 15-year period, between 1953 and 1968, that revealed successional movement toward the climax species. The oldest pines in the stand were about 250 years old and dated back to a fire. Disturbance, in the form of thinning some of the balsam fir understory, had taken place in the 1930's. The following trends were noted during the study period. There was an increase in species richness in the stand from 1953 to 1964. The red pine overstory was beginning to lose its dominance in the stand, and it was likely that the other conifer species and hardwoods would take over. Reproduction of red and white pine declined, probably due to a lack of forest disturbance to create favorable seedbed conditions.

IMPACT OF FIRES / CATASTROPHIC EVENTS

Fire has a major impact on the process of succession. Agee (1974) offers the following assessment of the effects of fire. Natural fires will have a major influence on plant succession, but the effect will rarely be detrimental where the objective is to maintain a natural vegetation mosaic. Natural fires will create irregularly shaped vegetation mosaics that vary as a function of fuel types and fuel moisture. Coniferous species with relatively thick bark will be favored over thinner-barked conifers and hardwoods, but sometimes sprouting hardwoods will be rejuvenated and favored over less fire-resistant conifers. As a result of the vegetative mosaic, faunal species diversity of the climax and successional types will be maintained.

According to Wright (1974), "fire interrupts the successful sequence toward climax. Geomorphic and edaphic factors in vegetational distribution are largely submerged by the fire regime, except for bog and other lowland vegetation. Fire recycles nutrients and renews succession." Wright and Heinselman (1973) offer the following observations. Fire maintains diversity...by maintaining a mix of successional stages in the total vegetative mosaic. The spatial scale of the mosaic is determined by fire size, surface or crown fires, and the natural fire rotation. Return intervals, intensity and fire size together determine the pattern of stand ages and successional stages. Fire may also control the local occurrence of plants through interactions with soils, slope, aspect, elevation, etc.

Wright and Heinselman (1973) go on to suggest that "stability may be promoted by the existence of the mix of successional stages,communities, and stand ages maintained by periodic fire. Fire exclusion, for example, might cause fuel accumulations, which could lead to large, intense fires and unnatural effects on regeneration. An aged, near-climax forest might also be far more susceptible to insect and disease outbreaks and to blowdowns. Its animal populations would be less diverse and probably less stable."

Wright (1974) maintains that fire suppression by humans prevents the frequent disturbances under which the forest develops and maintains diversity, and that elimination of fire and other perturbations may be the most profound effect of humans on wilderness systems. Bergeron and Dubuc (1989) made a similar observation during their study of succession in the landscape region of the southern border of the boreal forest in Canada. They predicted that with fire suppression, forests would become self-replacing and, in the long run, the only dominant species will be balsam fir and white cedar on mesic and hydric sites, and white cedar and black spruce on xeric sites.

Fire was an important factor in maintaining the presettlement forests in Itasca State Park and elsewhere. In the Itasca region, moderate intensity surface fires that eliminated understory but killed few mature trees occurred at 20-40 year intervals, while more intense fires that killed most of the stand and introduced new age classes occurred at 150-300 year intervals (Heinselman 1983). The fire cycles in Michigan's primitive forests were effective in maintaining all temporary forest types such as aspen, paper birch, jack, red and white pine (Graham, et al. 1963).

"A repeating cycling sequence of catastrophic fires with intervening light surface fires can lead to long-term dominance by white pine for several thousand years" with pulses of aspen occurring after each major fire (Frelich 1992). However, if a white pine stand is missed at random for several fire cycles, succession to northern hardwoods will occur. Windstorms will then blow down the mature white pine and the gaps will be filled in by hardwoods.

Although catastrophic windthrows can also impact on succession, the average return interval is 1,000 years (Frelich 1986). Therefore, such events are only infrequently involved in returning the forest to the temporary forest types and may actually encourage succession to climax as pointed out above.

POTENTIAL IMPACT OF CLIMATE CHANGE

Changes in climate have affected forest composition in the past and could affect successional progress in the future by changing disturbance patterns, such as fire frequency. A study by Johnson (1992) suggests that larger changes in fire frequency are controlled by large scale atmospheric circulation patterns while shorter-term changes are controlled by more local climate, landform and land use patterns. He determined that fire frequency in the Itasca region decreasedduring a wetter-cooler period between 1240 and 1400 a.d., increased during a warmer-drier period between 1400 and 1600 a.d., and decreased again during the cooler-wetter period that began again in 1600 a.d. Clark (1990) also found that fire regimes in northwestern Minnesota have been responsive to temporal climatic variability. Fire frequency intervals ranged from 8.6-10 years during warm/dry periods and from 13-43 years during cool/moister periods.

The history of white pine in Minnesota provides a good example of the impact climate has on stand composition and succession. White pine movement westward was favored by the warmer, drier conditions of the mid-Holocene period (Jacobson 1979). White pine was also favored by the period between 1450-1850, known as the Litle Ice Age, because drought and other aspects of climate change led to an increase in the frequency of disturbance (Stearns 1992). On the other hand, a change to a wetter, cooler climate can be a factor contributing to successional progress from white pine to northern hardwoods because the repeating cycle of fires that maintain white pine can be disrupted (Frelich 1992).

RED PINE

RED PINE STANDS IN ITASCA STATE PARK

In Itasca State Park, red pine stands were generally found on sandy and sandy loam soils with less calcareous material and lower moisture content (Lee 1924). Kurmis and Hansen (1969, 1972) and Hansen, et al. (1974) found that red pine regeneration was limited to dry, nutrient poor sites, such as the jack pine-bearberry types because pines cannot compete with moisture demanding herbs, shrubs and hardwoods on nutrient rich soils.

Cheyney (unk) described red and white pine stands he observed on tracts east of Lake Itasca as "scattered over the entire area." These stands were dominant along the lakeshore and the slope running down to it and to the south of this area. The percent of white pine in the mixture varied from 70% in the northern sections to 25% in the lower sections. The soil was much the same as that of the jack pine, but contained slightly more clay and had a higher moisture level.

The underbrush, which consisted of alder, aspen and birch, was thicker where the red pine predominated and much thinner where the white pine formed the bulk of the stand. Red and white pine stands were found to occupy the east slopes of ridges in one section that consisted of fairly high hills, irregular ridges and small sharp peaks separated by shallow valleys.

Cheyney (1947) attributed the lack of pine regeneration in Itasca State Park to deer browsing and shrub competition. He advocated intensive forest management to regenerate stands of red and white pine. Thinning of mature stands, brush removal, seedbed preparation and planting of pine seedlings were among the steps he cited as necessary to remedy the situation. A rotating schedule of regeneration plots was recommended in order to keep attractive sites available to tourists while maintaining the health of this forest ecosystem. Feeney, et al. (unspec.) cited a serious deer overpopulation problem in Itasca State Park in correspondence between November 1934 and February 1937. He recommended a drastic reduction in deer numbers in order to renew the red pine forests that had been failing to regenerate themselves due to overbrowsing of the seedlings. Hansen and Duncan (1954) observed that the lack of fire in Itasca State Park had led to the growth of a shade tolerant understory of balsam fir in stands of mature red pine, thus hampering red pine reproduction. In areas where the fir understory had been removed, red pine seedlings were sometimes able to establish themselves.

RED PINE STANDS IN GENERAL / OTHER AREAS

Red pine is found on a variety of soils, with different associates based on soil type. According to Rudolf (1990), red pine associates on coarser, drier soils are jack pine, aspens and oaks. On fine sands to loamy sands, red pine associates include jack and white pine, aspen, oaks, red maple, black cherry, balsam fir and black spruce. Whereas, on sandy loam and loam soils, red pine can be found associated with sugar maple, white pine, basswood, red maple, balsam fir, paper and yellow birch, red oak and white spruce.

Although mature red pine is fire resistant, fire can be devastating to young pine stands. The red pine community was consistently found close to bodies of water of 5 acres or more in the

Boundary Waters Canoe Area (Ohmann and Ream 1971), which may reflect the importance of the protection water bodies can provide from certain fires. Red pine was also found associated with lake landscapes in the southern part of the Canadian boreal forest, where the intensity of the fire regime is low (Bergeron and Dubuc 1989). High intensity fires create regeneration difficulties for red pine.

In red pine forests, the understory is generally open, with poor development of the tall shrub layer . On a 43 year old red pine plantation in Michigan, the understory was sparse, with only 4.2% of the total understory area covered by crowns of trees less than 6 feet high (Gysel 1966). The majority of these trees were red pine saplings that were found under small openings in the overstory canopy. The most uniformly distributed plant group in the understory was composed of a grass and a sedge.

As the red pine forest matures and the crown cover changes from near ground level to approximately 20 feet above the ground, populations of deer, rabbits, hares, squirrels and birds tend to decline (Gysel 1966). A lack of low-growing food sources and cover may become a limiting factor for many animal species, especially during the winter.

RED PINE REGENERATION

Several factors are critical for successful red pine regeneration, including adequate seed production and dispersal, appropriate seedbed conditions, lack of competition from other vegetation and favorable precipitation during germination and seedling establishment. Natural regeneration is not very dependable because the probability of favorable conditions coinciding is low (Benedict 1989, Benzie 1973a, and Ahlgren 1976). In north central Minnesota, such a combination of conditions in a given locality may occur only about once in 75-100 years (Rudolf 1990). Therefore, other methods of regeneration may need to be implemented to improve regeneration potential, including direct seeding, planting or manipulation of the site to enhance natural reproduction. Artificial regeneration methods that have been successful include the shelterwood system and clearcutting followed by machine site preparation and then seeding or planting (Benzie 1973a).

To secure red pine reproduction with the rapid shelterwood system, Bakuzis (1954) recommends initially removing the understory down to 5 square feet basal area per acre. For three years, the overstory basal area can remain at 120-180 square feet per acre, after which it should be reduced to 60 square feet per acre. The removal cut should follow about four years later.

SITE SELECTION

Regardless of the regeneration method applied, establishment and growth will depend on proper site selection. The characteristics of site that are important to red pine regeneration include soil properties, topography, type of vegetation present, fire history, etc.

Soil Properties

Red pine can grow on a variety of sites, but does best on well-drained sandy to loamy soils. It grows sporadically on heavier soils, probably because of its inability to compete with more aggressive species and the occurrence of root injuries on these soil types (Rudolf 1990) Fowells (1965a) reports that red pine can thrive on some structured lacustrine red clays, which restrict the hardwoods, but is stunted on soils with hardpans and on heavy lacustrine soils. Kurmis (1985) found that in Itasca State Park, red pine forest types are located on well-drained, loamy coarse sands to gravelly sandy loams and loams.

Red pine grows especially well on naturally subirrigated soils with well-aerated surface layers and a water table 4-9 feet deep (Rudolf 1990). According to Grant (1929) red pine does not have very specific soil requirements, but cannot endure drought or an exceptionally sterile soil. Yet, on rocky areas covered with organic soil, where the soil is thin and the water-capacity is accordingly small, red pine becomes the climax dominant (Stallard 1929).

Red pine grows well on soils that have a pH of 4.5-6.0, a silt-plus-clay content of 10-40%, a base exchange capacity of 2-11 m.e. per 100 grams, an organic matter content of at least 1.7%, a total nitrogen content of 0.03-0.04%, available P_2O_5 of 40-60 pounds per acre and available

K_2O of 40-200 pounds per acre (Fowells 1965a). Red pine may stagnate severely on soils deficient of potassium or be adversely affected by a strong concentration of iron and humus in the B horizon of the soil (Fowells 1965a). The problem of potassium deficiency can be remedied by application of potash containing substances (Heiberg and White 1950).

The site index for red pine on sandy soils may range from 45-75 feet at 50 years of age (Benzie 1977a). The site index on sandy soils in Minnesota was found to be higher on soils that had strong texture bands (15 cm. or more), were underlain by finer materials, or were developed within finer materials than on those soils that lacked texture bands or underlying finer materials. The difference was probably due to greater moisture storage in the first soils (Alban 1974). Surface soil (0-25 cm.) properties are more closely related to site index than are soil properties of the forest floor, subsoil or total mineral soil to a depth of 100 cm., within a given soil type, according to Alban (1974).

Topography

The topography of the site is important to red pine regeneration because soil moisture, temperature and protection can vary with aspect, slope and other geographical features. On a site in southwestern Wisconsin, soil moisture was compared on north and south facing slopes in both a hardwood forest type and a pine plantation (Stoeckeler and Curtis 1960). On each stand type, there was a systematic increase in soil moisture from the top of the slope to the bottom. This trend was more consistent on the north aspect than the south aspect. Hardwoods were able to hold more soil moisture than the pine plantation on the north aspect. But, on the south aspect, the two forest types had similar moisture levels. Furthermore, pine versus oak volume had a ratio of 3.5 to 1 on the lower south facing slopes. The authors concluded that conversion to pine may be appropriate and successful on the drier south facing slopes.

Pure stands of red pine were found on southerly and southwesterly slopes with adjacent open areas by Blowers (1960) He surmised that succession to shade tolerant trees was probably retarded in these stands due to the drier habitat caused by earlier warming and loss of snow cover in spring, increased runoff due to slope, and prevailing southwesterly summer winds. Although there was no succession to shade tolerant trees on these sites, there was no evidence of pine regeneration, either.

Certain topographical features may be important to red pine reproduction because they reduce the intensity and/or the extent of fire in the stand. Although fire is an important factor in seedbed preparation and control of competing vegetation, severe fires can eliminate seed sources and regeneration can be lost. Van Wagner (1970) found that the most desirable fire to promote red pine regeneration is a large one in which the fire behavior varies considerably on a small scale. That way, some seed trees are retained, while enough area is cleared to encourage regeneration. Such fires occur in areas with natural fire barriers such as rough topography or lakes. Swain (1980) also found that complex, or rugged, topography contains firebreaks that can protect patches of conifers that can seed in surrounding areas, and claimed that firebreaks were essential for the survival of conifers, especially when fires occur at intervals shorter than the reproductive age of the trees.

In the BWCA, Heinselman (1973) found that red and white pine were more abundant on areas that were burned less frequently or intensely. Such areas include swamps, valleys, ravines, lower slopes of high ridges (esp. east or northeast faces), islands and east, north, northeast or southeast sides of lakes or streams. Any site on the favorable side of a possible firebreak was more likely to support these species. In the southern Canadian boreal forest, red pine was favored by the lake landscape on islands, where the fire regime was of low intensity (Bergeron and Dubuc 1989). River drainages, rock outcroppings, glaciers or snowbanks, old fires and vegetation changes may also limit the spread of fire (Wakimoto 1984).

Vegetation Present

The vegetation present on the site may give an indication of the likelihood of success and the associated costs if red pine regeneration is attempted. For example, red pine is able to invade and replace jack pine wherever a good stand of jack pine is attainable (Stallard 1929).

Conifers are usually more productive than aspen on poorer sites, so conversion to conifers may be appropriate on such locations (Perala 1977). Sites where aspen fails to reach pulpwood size before becoming decadent are good candidates for conifer restoration because aspen and undergrowth are less aggressive and thus are most easily displaced (Shirley 1945). Areas severely burned and supporting only scattered aspen seedlings can usually be cheaply prepared for planting by plowing furrows and should be given high preference. But, if aspen is 15 feet or taller and is dense, conversion to conifers will be expensive.

Fire History

While red pine regeneration benefits initially from fires that prepare the seedbed and eliminate competing vegetation, severe or frequent fires are detrimental to its success. Rouse (1988) claims that open-grown red pine needs at least one fire-free period of 20-25 years to produce seeds for regeneration. Red pine is favored by fire cycles of 100-150 years (Frelich 1992). In the BWCA, red pine was historically subject either to frequent, light surface fires (every 1-25 years), or infrequent, severe surface fires (one every 25 years or longer), and long return interval, crown fires (every 100-300 years) (Hendee et al. 1978). Since historic fire boundaries tend to be reinforced in successive fires, a mapping of historic fires would be a good predictive tool (Wakimoto 1984), along with information about fire frequency in the area. This information may be useful in selecting a site on which to attempt red pine regeneration.

DIRECT OR NATURAL SEEDING

Direct seeding of red pine has not been widely successful, except in northeastern Minnesota on well-prepared sites, if frequent rain storms occur during the first few months after germination (Benzie 1977a). Shirley (1937) found that direct seeding success was limited in red pine due to its slow juvenile growth, which results in it being crowded out by more aggressive vegetation. At least one, and maybe more weedings are necessary to improve direct seeding success.

Young seedlings on direct seeded sites are susceptible to heat injury. To reduce this threat to seedling survival, planting sites should be limited to those that have fairly high water-retaining capacity or sandy, open sites with a shallow water table (Stoeckeler and Limstrom 1942).

Seeding in autumn or early spring stimulates early and prompt germination, which can also help to reduce heat injury to seedlings.

Natural regeneration can occur after fire or logging, on sites with a good seed source. Areas where fires occur in late summer or autumn before seed shed create a favorable environment for natural regeneration (Ahlgren 1974 and 1976). But, on sites where spring and summer fires occur, invading vegetation can become established and provide serious competition before red pine seed is available in the autumn. In spring, the litter layer is winter cured and dry, and the duff fermentation and humus layers are moist. Wildfires spread quickly in red pine stands, but burn shallowly, causing little damage to the soil or roots. Vigorous re-sprouting of hardwoods and shrubs normally follows these spring fires. In the summer, moisture content of herbaceous fuels is high, making wildfire occurrence unlikely.

Logged sites with a good seed source can provide the benefit of seedbed preparation without the post fire ash that stimulates early herbaceous growth and inhibits red pine germination (Ahlgren 1976). Corson, et al. (1929) found that a red pine stand in Itasca State Park that was cut during a very heavy seed year, after the seed had ripened, reproduced to a dense stand of red pine. Whereas, areas that were cut before the seed had ripened came into brush, jack pine or aspen depending on the available source of seed. Therefore, the timing of logging, like fire, seems to be important to successful red pine reproduction from natural seeding.

Seed Production and Dispersal

Due to the irregular and infrequent intervals of good seed production, natural seeding from red pine seed trees has not been very successful (Benzie 1977a). Good seed crops occur only once every 5-7 years, with bumper crops occurring only once every 10-12 years or more (Ahlgren 1976, Benzie 1973a, Rudolf 1990 and Fowells 1965a). Because red pine seed stored in the soil loses its viability quickly (Ahlgren 1979), the infrequent regeneration opportunity will be lost if these bumper crops do not coincide with favorable germination conditions. According to Rudolf (1990) the seeds can lie dormant for 1-3 years before germination if conditions are dry.

The general consensus is that seed production begins when the tree is 20-25 years of age in open-grown trees and at 50-60 years of age in closed stands. Fowells (1965a) reports that seed production is usually best in trees from 50-150 years of age, with an average production of about 1/2 bushel of cones.

Stand quality can affect cone production. In a mature, medium-stocked stand, the number of cones produced in a good seed year ranges from 50 for unthrifty trees to 725 for open-grown trees. In an overstocked stand, only a few trees may produce cones and the seed fall may average less than 10 seeds per tree (Fowells 1965a). Benedict (1989) reports that trees more than 100-200 feet apart experience poor seed production and dispersal.

The number of viable seeds per cone can range from 14-45, with an average of 20. A high proportion of the seeds are viable when the cones have become purple with reddish-brown scale tips (Fowells 1965a). Although seeds may be disseminated up to 900 feet from the parent tree, the effective range is about 40 feet (Rudolf 1990 and Fowells 1965a), a factor that needs to be considered if attempting regeneration through the use of seed trees. Rodents consume large amounts of pine seed once it reaches the ground and can be responsible for destruction of as much as 50% of the crop (Fowells 1965a), further compromising the potential for natural regeneration.

Seedbed Requirements

Proper seedbed conditions are essential to red pine seed germination and early survival. Because red pine seedlings have short, slow growing vertical roots, germination and early survival are best on exposed, mineral soil and associated thin moss, which keeps the ground compact, moist and relatively free from competition (Ahlgren 1976). Rudolf (1990) recommends conditions that favor high moisture content in the seed, such as a fine sand seedbed, thin moss or litter, a water table within 4 feet of the soil surface, some shade, abundant precipitation and a light covering over the seed.

Germination and early survival are inhibited by thick litter, sod or heavy ashes of recent burns (Ahlgren 1976 and Cheyney 1942), and are reduced at a pH of 8.5 or higher and full sunlight for an average of four hours per day (Fowells 1965a).

Bakuzis (date unk.) indicates that proper seedbed conditions can result from fire, windfall or erosion. However, there is some inconsistency in the literature about the effect of fire on seedbed preparation for natural regeneration. Hansen (1967) found that red pine seeds must fall on fresh or recently burned areas in order to germinate and reproduce. Rudolf (1990) states "In nature, red pine stands become established following fire, the only natural agent capable of providing most of the conditions required for natural red pine reproduction." In a prescribed burning experiment, first year regeneration was greatly favored by severe fire over light fire that burned only through the top layer of duff (Van Wagner 1965).

Yet, as stated above, pine reproduction does not succeed in the heavy ashes of recent burns and Ahlgren and Ahlgren (1960) found that germination and very young tree seedling growth has sometimes been reported to be poorer on burned soil. Perry (1935) also found that red pine growth was better on unburned soil. The major drawback of fire seems to be related to those cases where heavy ash is produced. Under those circumstances, optimum germination is not achieved until several years after the fire when ash minerals have been reduced by leaching (Ahlgren 1976).

Timing of fire to precede heavy natural seed production by one or more years may be a way to take advantage of the positive aspects of fire, while avoiding the drawbacks. Van Wagner and Methven (1977) recommend the use of prescribed fire to manipulate events to encourage natural regeneration. Prescribed fire can be used to prepare a bare mineral soil seedbed or one with substantially reduced duff cover and competing vegetation. They suggest that a good seed year would be ideal if it occurred one year after the site has been prepared by prescribed fire. However, they state that it is not necessary because a well-prepared site should be receptive to pine regeneration for several years post-fire.

Site Preparation

Red pine regeneration is impeded by a heavy organic layer over the mineral soil seedbed and by competition from other vegetation, especially in the understory (Shirley 1945). According to Ahlgren (1974), pine seedlings have short, slow growing vertical roots and so survive best in mineral soil or reduced, burned humus one inch or less in depth. Various measures can be taken to improve regeneration conditions including clearing of overstory and brush, soil scarification and burning to remove competing vegetation and remove litter from the soil (Jaakko Pöyry Consulting1992).

Fire has been useful in creating more favorable conditions for regeneration. However, there are varying recommendations about the type and severity of fire that is preferable. In a mature red and white pine stand that was succeeding to balsam fir, two consecutive annual fires were successful in restoring the conditions necessary for initial pine regeneration (Methven 1973). The fires were gentle and consumed only part of the surface litter, leaving the duff untouched. Balsam fir was eliminated with one fire, and shrub competition was retarded, but not eliminated, with two consecutive fires. Van Wagner (1965), however, reported conifer regeneration has been observed to be better on sites where severe fire has occurred than on sites where a light fire has burned only through the top layer of duff. He further reported that in prescribed burning experiments on a red and white pine stand, first year regeneration and survival of pine seedlings was greatly favored by severe fire.

The proportion of bared mineral soil exposed after prescribed burning may depend on the original amount of moisture in the bottom layer duff. In one study, the bottom layer duff was appreciably reduced or removed only when its moisture content was less than 40% and fire danger was high or extreme (Van Wagner 1965). However, Van Wagner (1970) reported in another study that sufficient duff is removed only when its moisture content is about 60% or less.

Cultivation was found to stimulate red pine regeneration in the Chippewa National Forest, where natural regeneration had been inconsistent (Shirley 1933). Disking provided the seeds with protection from birds and rodents, with access to the more moist soil layers and freedom from competition by surface vegetation. Disking completely once provided the most favorable results, but adequate results were achieved by incomplete disking once at intervals. For best results, it was recommended that cultivation be done in the fall of a good seed year.

Clearing away some competing vegetation is important to encouraging successful regeneration, but clearcutting does not seem to be necessary. Shirley (1945) found that the success of regeneration was dependent chiefly upon the absence of intense competition from subordinate vegetation. The light and root competition from overstory trees were of secondary importance. Approximately 35% of full sunlight, or an overstory crown density of 0.67, offers satisfactory conditions for seedlings to become established (Fowells 1965a), but establishment is uncertain with light values below 17%. Low understory basal areas, under 18 sq ft per acre, were found by Bakuzis (1954) to be associated with greater red pine reproduction. Pine reproduction did not occur where understory basal area exceeded 26 sq ft per acre.

Although red pine is low-mid tolerant of shade, it thrives best in partial shade during the first year stages of growth (Ahlgren 1974). Some shade was found to favor germination and survival of red pine seedlings, especially on drier soils (Shirley 1945). And, on soils of clay-sand deposits or sandy loam, Thomas and Wein (1985a) found that the emergence of red pine was not significantly affected by herbaceous and shrub vegetation, which provided a natural shelter for the seedlings. However, insufficient light was found to lead to poor root development in pine seedlings and an increase in susceptibility to drought injury (Shirley 1932a).

Red pine seedlings will not grow under dense brush (Rudolf 1990), and are seriously compromised in the undergrowth of an aspen stand (Shirley 1941). Therefore, shrubs, such as hazel, and aspen must be eliminated prior to seeding (Tappeiner 1971). Either a series of gentle summer fires or one summer fire followed by a prolonged drought are the most effective in eliminating competing understory shrubs and hardwoods (Buckman 1964a). Conifers can be introduced successfully after logging mature aspen stands, especially if logging is accomplished in the summer because this will result in less sprouting (Shirley 1941). Repeated spring fires are effective in clearing areas dominated by aspen and in reducing the abundance and vigor of aspen suckers (Buckman 1965).

PLANTING SEEDLINGS

Benzie (1977a) found that the most reliable method of establishing a red pine stand is to plant nursery-grown trees. Many factors should be considered before planting in order to ensure the greatest success, however. These factors include the source of seed, site selection, underplanting, benefits from overstory, planting stock, climatic injury, protection from enemies, ground preparation, method of planting, care and cost of plantations (Rudolf 1937).

Proper site selection is key. For example, Stoeckeler and Limstrom (1942) found that the single most important factor to success during the first year of planting on light, sandy soils is normal rainfall. During drought years, a shallow water table had a marked impact on first year survival of planted trees, with survival significantly higher on subirrigated areas (where the water table is from 3-6 feet from the surface) than on upland areas (where the water table depth averaged 9 feet). The success on the subirrigated sites was due to an increased availability of soil moisture to the young seedlings. Areas near swamps that serve as winter deer yarding grounds should be avoided as plantation sites because deer are detrimental to young seedling survival (Shirley 1941).

The size of the planting stock and time of planting are also important. The use of larger stock will hasten early growth and increase probability of success (Shirley 1941). The minimum recommended age of red pine stock is 3-4 years. Stoeckeler and Limstrom (1942) also found that large age classes have somewhat better survival and larger root systems at the end of the first two growing seasons. In northern Minnesota, red pine should be started as early as possible, preferably between May and July (Alm and Schantz-Hansen 1970). Heavy soils are subject to frost heaving so planting on them should always be done in the spring (Shirley 1941). Planting on sandy soils can be accomplished in the spring or fall; however, fall planting is not as successful (LeBarron et al. 1938). The use of tubelings allows for successful outplanting in Minnesota during the growing season, between June and August (Alm and Schantz-Hansen 1970).

The preferable method of planting is the deep-hole method, where the roots are spread over a mound or wedge of soil built in the center of the hole (Shirley 1941). On sand plains in lower Michigan, survival and height growth were seriously compromised by cramped root systems, where the bulk of the roots were in a single plane (Rudolf 1939). The cramped root systems resulted from the use of the slit method of planting. Plantations established by the deep-hole method had a 25% greater survival than those planted by the slit method.

Shirley (1941) recommended close spacing of plantations because it shortens the time before the crowns close and consequently the time during which the planted trees must be protected from competing vegetation. Benzie (1977a) recommended that trees be planted at 10x10 foot intervals and suggested that closer spacing, such as 5x5 foot intervals, could be used but may necessitate thinning if the plantation is very successful. However, Cheo (1946) found in thinning experiments that growth was best on sites where spacing was maintained at 6x6 or 7x7 foot intervals. Growth was less at spacing intervals of 4x4 or 9x9 feet, probably due to the greater demands upon the limited soil moisture by the denser stand and the fact that the more open stand was exposed to a higher evaporation rate, greater wind movement and other desiccating factors. These findings led to the suggestion that wide space planting may be unfavorable to rate of growth.

Site Preparation

Competition for light, water and nutrients should be eliminated before planting red pine seedlings. In planted seedling studies, the removal of competition for light produced a larger growth response than the removal of competition for moisture. But, the maximum growth response occurred only when both types of competition were eliminated or greatly reduced (Strothmann 1967). Competition from the subordinate vegetation is of primary importance as a deterrent to conifer reproduction, while shade and root competition from the overstory are of secondary importance (Shirley 1945). Actually, leaving some overstory intact can be beneficial to young seedling survival as is discussed in the section on underplanting.

Mechanical equipment, herbicides or prescribed burning can be used to prepare the site for planting (Benzie 1977a). Site preparation can range from minimal to complete; there are tradeoffs from each extreme. Minimum site preparation of only the planting sites offers the most site protection but may require frequent follow-up release. Complete site preparation will reduce the need for follow-up release, but may expose the site to erosion or severe drying (Benzie 1977a).

Furrowing or scalping is necessary to give planted trees at least 2-3 years to establish themselves in order to compete successfully with lower vegetation (Rudolf 1937). Furrowing is recommended by Shirley (1941) as the most effective means of counteracting root competition from undergrowth. He indicated that furrows should be 3-6 inches deep and should have flat bottoms 14 inches wide. He recommended the use of an Olympic plow followed by a heavy furrowing plow to clear a strip 5 feet wide of brush and small aspen trees.

Fire can be successfully used to eliminate competing vegetation. Prescribed burning is usually more effective for site preparation soon after harvesting when slash accumulations provide plenty of fuel for a hot fire, according to Benzie (1977a). However, in a study of site preparation prior to planting tubelings, mortality was high on sites that were burned once in the spring of the year that the seedlings were planted (Alm and Schantz-Hansen 1970). Whereas, on sites where fires occurred 3 and 1 year prior to planting, vegetative competition was minimal and planting conditions were nearly optimal for red pine survival.

UNDERPLANTING

Partial shade is beneficial to the early survival of planted stock, as determined by LeBarron et al. (1938) in a planting study that compared survival under brush cover to open sites. Best results are obtained by leaving intact sufficient overstory to provide shade for each seedling during some portion of the day (Shirley 1941). The beneficial effect of shade cast by trees and shrubs is often sufficient to offset any injurious effects due to competition, especially on comparatively open, dry sites (Rudolf 1937). For example, on light, sandy soil in a year of severe drought, a light canopy of aspen 15-20 feet high, with a light intensity of 75% at breast height and

56% at 0.05 feet from the ground, made the difference between success and failure in a 2-1 red pine plantation as compared to open areas (Stoeckeler and Limstrom 1942). There was a marked reduction in evaporation rate under the aspen stand, which was often only 1/10 of that recorded in the open.

Underplanting in hardwood stands is not recommended unless early release cuttings are planned (Benzie 1977a). In a study at the University of Maine Forest, underplanting results were best on sites where early release from hardwoods was heavy, but not complete (Geerinck et al. 1954), possibly because the light canopy that remained retarded further growth of hardwood sprouts.

The best time to remove the overstory is somewhat unclear. Shirley (1941) recommends that conifer seedlings be completely released from the overstory when the seedlings have reached heights of 4-6 feet. In the wild, red pine seedlings may take 4-10 years to reach breast height and overtopped seedlings may take 15-16 years (Rudolf 1990). Another study showed that full sunlight is required for maximum height growth by the age of 6, even though red pine can be established and achieve maximum height growth with 45% full sunlight up to the age of 5 years (Logan 1966). And yet another study showed that red pine seedlings seem to require full or nearly full sunlight to obtain the greatest weight gain (Shirley 1945). Maximum dry-weight increase in red pine occurred at 98% of full sunlight, while maximum height growth occurred at a light intensity of less than half that amount. The relative importance of dry weight gain vs. height growth, in terms of survival, may need to be evaluated to determine when the optimal time will be for overstory removal.

TREE MORTALITY / SURVIVAL

Competition from Other Vegetation

Competing vegetation can continue to threaten pine seedling survival even after establishment is certain. The interference of neighboring plants increases susceptibility to drought injury, due to poor root development under insufficient light (Shirley 1932a). Benzie

(1977a) indicated that red pine may need complete release from shrubs and other low vegetation by the end of the third growing season. Release can dramatically enhance the growth of red pine as observed by Wehr et al. (1992) in release studies.

Even if the seedlings have been established successfully for a number of years, competing vegetation can take over and reduce or eliminate advanced pine regeneration. For example, in a red and white pine plantation that had been successfully established, serious aspen competition developed after the ninth year and destroyed about one-half of the pine regeneration over the next 7 years (Eyre 1933). It is recommended, therefore, that periodic weedings and release cuttings be planned on a long-term basis, especially on sites where aspen can become a threat.

Hardwood reproduction can be avoided by keeping overstory basal area at a high level, but brush cannot be kept down with overstory alone (Bakuzis 1954). Brush also persists under understory basal area of 40-50 square feet per acre or more. Therefore, the main goal is to avoid its invasion by keeping the understory basal area over 60 square feet. Understory basal area is more important than overstory basal area to oppress brush. Increasing understory basal area with decreasing overstory basal area have contributed to an increase of balsam fir reproduction in Itasca State Park. Balsam fir reproduction can be redued by increasing overstory and understory basal area at the same time.

Release can be accomplished by hand cutting, prescribed fire on older stands, or the use of herbicides. Hand cutting is labor intensive and may need to be repeated several times at 2-3 year intervals (Benzie 1977a). Burning is effective in eliminating shrubs and small hardwoods, but cannot be used until the red pine has passed the age of vulnerability (see Fire Effects section below). According to Van Wagner (1970), undesirable hardwoods can be controlled by two consecutive annual fires. During the early years, herbicides may offer the most practical means of release. 2,4-D and 2,4,5-T can control most of the deciduous woody competition without injuring red pine if spraying is done soon after pine leader growth is complete and the terminal bud is set, around mid-July. Spraying should be completed before the middle of August for the best control of hardwoods (Benzie 1977a). Raspberries are resistant to 2,4-D but can be controlled with hexazinone (Wehr et al. 1992).

Impact of Deer and Other Animals

Snowshoe hares, cottontail rabbits and deer may destroy red pine seedlings through overbrowsing, and porcupines may destroy saplings to mature trees through girdling. Red pine was found to be the least desired of the three common pines as deer food (Swift 1948), but was also found to be the most sensitive to browsing (Orke 1966). Repetitive browsing seems to be a key factor in reducing tolerance. Overbrowsing may be tolerated for 1-3 years by well-established conifers without negatively impacting on growth rate and form, but not for prolonged periods of time (Marshall et al. 1955). In Itasca State Park, browsing of conifer seedling leaders was found by Orke (1966) to be common until the seedlings reach 4.5 to 5 feet in height, after which the leaders were seldom browsed.

Red and white pine are preferred over other conifers and hardwoods as winter food sources by porcupines in Itasca State Park. Porcupine feeding was observed by Anfang (1972b) to be most common on red pine with an average diameter of 12-14 inches. Most scarring on the red pines was at the base of the tree. Porcupine feeding can result in reduced quality or growth and possibly death of the tree. Once a porcupine finds a suitable tree, it will return to that tree repeatedly.

Impact of Insects and Diseases

The red pine cone beetle destroys cones of the red pine and is prevalent throughout the red pine range. This beetle is especially problematic in seed production areas, where it can be responsible for the loss on average of 20% of the seed cones. Adult beetles overwinter on the ground, which makes them vulnerable to prescribed burning if it occurs between October 22 and May 10 (Miller 1978).

Fire Effects

Young stands of red pine are susceptible to fire injury, especially when planted in pure, dense stands (Rouse 1985 and Benzie 1977a) because of the well-aerated litter layer under the stands and the continuous crown structure. The flaky bark also helps a fire jump into the crown (Rouse 1988). To minimize losses from fire, young stands should be protected by firebreaks or barriers, pruned to reduce the risk of ground fires reaching the crowns, and thinned or selectively cut to reduce contact between crowns.

Bark thickness appears to be the primary factor in determining whether a tree is fire resistant or not (Reifsnyder et al. 1967). The older the tree, the thicker the bark and, consequently, the more fire resistant the tree (Rouse 1988). In red pine, fire resistance has been documented to be effective at various ages, heights and diameters. Rouse (1985) and Van Wagner (1970) reported that red pine has developed a fairly fire resistant bark by the age of 50 years. Rouse (1985) also reported that fire resistance is effective once the tree reaches 60 feet in height, while Rudolf (1990) reported that fire may kill red pine in stands up to 69 feet tall. While tall trees are still susceptible to crown damage, they may survive even if up to 85% of the original crown is scorched (Rouse 1988).

Factors such as timing and intensity of fire and the pre-fire conditions of the stand may be more important than age or size in determining the vulnerability of red pine to fire. These factors will affect the extent of crowning and defoliation, the cambial temperatures reached and the duration of heating of the bark, all of which can affect the ability of the tree to survive. Van Wagner (1965) specifically, found in prescribed burning experiments that size was a minor factor compared with the proportion of crown killed, in determining pine mortality. Burgess and Methven (1977) found that 30 year old pine was able to survive fire of variable low to moderate intensity with little loss at a site in Chalk River, Ontario. In a fire that occurred in April, prior to bud opening, red pine was able to withstand extensive defoliation (up to 95%) with low mortality. Had the same fire occurred between May and September, mortality would probably have been much greater (Sucoff and Allison 1968).

The lethal temperature for cambial death during fire was found to be 60 degrees C. by Johnson (1992). He further determined that red pine 40 cm. in diameter could survive for about 12-13 minutes in a fire. Mature red pine can sustain sizable fire wounds without compromising the health of the tree (Verrall 1938). Resins are secreted into the fire wounds making them resistant to decay even when they cover one-fourth of the circumference of the tree and have been present for more than one-half century.

Length of Life

A red pine stand can be expected to thrive until an age of 140-150 years and longer. Individual trees will maintain vigor and growth at the age of 250 years, but the stand will not remain intact (Spurr and Allison 1956).

STAND MANAGEMENT

Stands of red pine can be managed toward a variety of goals including maximum timber production, recreational value, or to improve wildlife habitat. Thinning, whether natural or artificial, can aid in the maintenance of a healthy, well-stocked stand. Absence of thinning in a fully stocked red pine stand can lead to stagnation of growth and a loss of timber production. By mixing red pine with jack pine or other short-lived species, natural thinning can occur which will favor red pine (Spurr and Allison 1956).

A maximum carrying capacity (above which net growth will decline) was calculated by Spurr and Allison (1956) to be 210 square feet per acre for pure red pine in northern Minnesota on an average quality outwash sand site. In thinning experiments in the Cloquet Experimental Forest, red pine stands were found to be able to carry a density of 1,500 trees per acre up to 35 years without danger of stagnation (Schantz-Hansen 1952). At a density of 2,400 trees per acre, stagnation was apparent in 35 years along with volume loss in timber production. At a density of 500-800 trees per acre, there was a loss of productivity in the early years because the trees were not able to fully utilize the capacity of the site.

Benzie (1977a) recommends the following strategy to manage a red pine stand for recreational purposes. Young stands should be maintained near the minimum recommended for stocking to obtain large trees as soon as possible, but older stands should be managed near the upper limits to reduce development of unwanted understory plants and increase the opportunity to extend the rotation. New stands should be established regularly to provide continuous stands of large, old growth trees for the future. Uneven-aged management may be necessary in some special areas to maintain a continuous stand of mature trees.

Anfang (1972a) recommends a program of selective cutting/thinning to manage red pine for recreational and aesthetic purposes. Thinning and release will open up the stand, create a park-like appearance over time, and allow released trees to grow faster and produce larger sized trees sooner. Red pine thinnings should begin at about 20 years of age. Red pine may also be grown at low densities of about 40-80 square feet of basal area per acre to get large diameter trees faster. Pruning increases the aesthetic value of a stand by clearing the area of dead and unsightly branches and stubs.

In order to manage a stand for wildlife habitat, Benzie (1977a) recommends that the stands be maintained near the minimum recommended stocking. This will favor a greater variety of understory plants that are favored as food sources.

WHITE PINE

WHITE PINE STANDS IN ITASCA STATE PARK

In Itasca State Park, white pine was found to occupy clay soils with higher calcium levels and greater moisture holding capacity (Lee 1924). Hansen and Brown (1950) observed that the moderately shade tolerant white pine was able to reproduce under the less dense brush of the mixed red and white pine stands and the brush-free jack pine stands. With fire suppression, dense brush, especially hazel, had become widespread in the Park. White pine was found by Kurmis and Hansen (1972) to be better adapted to the ecological conditions of the Park, than were red or jack pine, because it was able to withstand competition from dense shrubs for some time.

Despite its ability to become established in areas with dense brush, white pine was found to persist only on dry, nutrient poor sites (primarily jack pine-bearberry) and mesic, nutrient rich sites in the maple basswood-leatherwood type. These were the only stand types where white pine seedlings over 10 years of age were found by Kurmis and Hansen (1969 and 1972). Furthermore, satisfactory growth was only noted on the jack pine-bearberry sites.

Webb (1985) found that white pine has been able to regenerate well to the seedling stage on rotting logs and stumps that result from windthrows and blowdowns. However, most seedlings are eaten by deer and don't reach the sapling stage.

Cheyney (unk.) described red and white pine stands he observed on tracts east of Lake Itasca as scattered over the entire area. They were dominant along the lakeshore and the slope running down to it and to the south of this area. The percent of white pine in the mixture varied from 70% in the northern to 25% in the southern parts of the Park. The soil was much the same as that of the jack pine, but contained a little more clay and had a little higher moisture level. The underbrush, which consisted of alder, popple and birch, was thicker where the red pine predominated and much thinner where the white pine formed the bulk of the stand. Red and white pine stands were found to occupy the east slopes of ridges in one section that consisted of fairly high hills, irregular ridges and small sharp peaks separated by shallow valleys.

Cheyney (unk.) recommended a major planting project be undertaken to restore pines in the Park. He felt that preference should be given to white pine and that areas of jack pine should be cleared and planted to white pine. He advised that clearcutting should be used instead of a selection system because a more dense stand, free from underbrush, can be obtained.

A small scale investigation of the effects of hazel competition and browsing on planted white pine seedlings was carried out near the Mary Lake deer exclosure from 1983 to 1987 (Steingraber 1989). The purchased seedlings were 20-35 cm tall. Four sites in a red pine stand were selected to represent (1) browsing & hazel competition, (2) browsing & no hazel competition, (3) no browsing & hazel competition, and (4) no browsing & no hazel competition. In each site, 26 seedlings were planted in a grid with 1 m spacing. Four years later, in August 1987, 100% had been browsed and most were shorter than when planted. Only those in the no browsing and no hazel competition site showed an increase in height.

WHITE PINE STANDS IN GENERAL / OTHER AREAS

White pine invaded eastern Minnesota from the east about 7,000 years ago. Further westward movement was retarded for several thousand years because of the warm, dry climate of that period. It reached the Itasca region about 2,700 years ago (Wright 1968) and reached its westward limit of distribution about 500 years ago (Jacobson 1979). The diverse climate from about 1450-1850, known as the Little Ice Age, favored white pine because of the increased frequency of disturbance due to drought and other aspects of climate change. Major fires probably initiated extensive stands of white pine during this period (Stearns 1992).

In the Boundary Waters Canoe Area, white pine communities were found on moister, but low nutrient soils. Stands were located on northeast to south facing mid-slopes to ridgetops (Ohmann and Ream 1971). Stands of white pine tended to be even-aged because fires cleared the underbrush for seeds from surviving trees (Wright 1974).

In northern Minnesota, the best developed white pine stands occur on mesic sites of lake margins and lower slopes, with optimal growth on moderately well-drained deep loams and sandy loams (unspecified 1986). However, on the lakeshores and islands situated at the southern limit of the boreal forest, white pine was found on the xeric sites (Bergeron and Dubuc 1989).

White pine is found mixed with hardwoods on medium and light soils where white pine has the advantage. Successful pine regeneration usually precedes or coincides with hardwood regeneration but doesn't usually follow it. In forests less than 60 years old, white pine more than 10 years younger than the hardwoods is rare. White pine often regenerates as isolated individuals surrounded by hardwoods if the density and competition from hardwoods is not too severe (Hibbs 1982).

WHITE PINE REGENERATION

The same factors that are important for red pine regeneration are important for white pine regeneration including adequate seed production and dispersal, appropriate seedbed conditions, a lack of competition from other vegetation and favorable precipitation during germination and seedling establishment. White pine germinates more successfully than red pine on very thin litter and is more tolerant of shade, but is still dependent on fire to eliminate faster growing trees competing for light (Benedict 1989).

The optimal conditions for white pine regeneration are a seedbed either bared to mineral soil or with its duff cover substantially reduced (several centimeters thick or less), relative freedom from competition by shrubs and understory trees of undesired species, a live overhead seed source, and considerable opening in the overhead canopy (Van Wagner and Methven 1977). Prescribed burning the year prior to a good seed year would create the proper conditions for white pine regeneration.

Fire is an important factor in natural white pine regeneration. In a study of white pine forests in Quebec, regeneration was found only on sites where burning had occurred, resulting in an opening or thin canopy cover and proper seedbed conditions (Maissurow 1935). White pine trees were found to be even-aged and belonging to the oldest age class in the stand, indicating that their establishment resulted from some type of disturbance that had cleared the area of trees, such as burning or windfall. It would appear, however, that fire isn't essential for white pine regeneration, at least in some habitat types. Burgess and Methven (1977) observed that white pine regeneration was occurring under red and jack pine and would eventually dominate the stand at a Chalk River, Ontario site even though fire had been absent from the region.

The introduction of logging into the white pine forest has had a negative impact upon white pine regeneration. After logging, white pine does not always re-establish itself, as observed by Maissurow (1935) in his study of white pine forests in Quebec. He found no regeneration in stands that had been logged. This lack of white pine regeneration and persistence is due to removal of seed sources over larger areas, substitution of logging for fire as the major type of disturbance, poor seedbed conditions for pine in second growth forests, ability of hardwoods to revegetate forests rapidly by sprouts under short-rotation harvest systems, and deer browsing (Frelich 1992).

Artificial regeneration techniques that have been attempted to improve white pine regeneration include direct seeding, planting seedlings, site manipulation to improve seedbed conditions and various cutting systems from clearcutting in blocks or strips to shelterwood and group selection cutting. Shelterwood cutting has been the most versatile reproduction method used (Little et al. 1973).

SITE SELECTION

Soil Properties

White pine has been found on a variety of soils from well-drained fertile soils, such as loams and clays (Grant 1929) to excessively drained or moderately drained sandy or stratified sand and gravel deposits (Wendel and Smith 1990). The optimal site types for white pine, based on moisture and nutrient levels, are reported by Kotar (1992) to be dry mesic and nutrient poor to medium.

Although white pine grows best on well-drained deep loams and sandy loams (unspecified 1986), it is more competitive on well-drained sandy soils with low to medium site quality because hardwoods are not as competitive on these sites (Wendel and Smith 1990, Fowells 1965b, Robbins 1984). White pine does well on sandy loams and silt-loams with good or impeded drainage if there is no hardwood competition during establishment. It does not do well on heavy clay soils, poorly drained bottom lands, upland depressions (Wendel and Smith 1990) and soils with groundwater less than 2.5 feet below the surface (Robbins 1984).

In northern Minnesota, the major soil groups found in the white pine range are Eutroboralfs, Haplorthods, Udipsamments and Hapludalfs (Wendel and Smith 1990). Corson, et al. (1929) found white pine on loam soils in the Cloquet Forest of Minnesota and on light sands in New England where precipitation is about twice that in Cloquet, suggesting that white pine readily accepts increased moisture as compensation for decreased soil fertility.

According to Fowells (1965b), the optimum supply of nitrogen to young seedlings is 300 ppm, of phosphorous is 350 ppm, of potassium is 150 ppm, and of calcium is 200 ppm.

Topography

The best developed white pine stands in northern Minnesota were found to occur on mesic sites of lake margins and lower slopes and on sites having a history of less intense fires than drier red pine forests (unspecified 1986). Topography is important to white pine regeneration because of the effect that topography can have on fire frequency and intensity and the occurrence of white pine blister rust. See the section on topography under Red Pine Regeneration for a discussion of the topographical features that affect fire frequency and intensity.

White pine blister rust is favored by a cool and moist microclimate and is best controlled by selecting low hazard sites on which to plant white pine. Topography and bodies of water can affect microclimate and thus the threat of white pine blister rust infection. The base of a north facing slope can be expected to favor infection (Anderson 1973). Jones (1992a) also noted that, among other factors, topography, slope, aspect and proximity to water affect the incidence and severity of blister rust in Minnesota. Robbins (1984) points out that the risk of infection is high in topographic depressions and at the bases of slopes; while the risk is intermediate where white pine is planted in large forest openings, in open fields, on steep slopes or on hill tops.

Vegetation Present

White pine can become established over a wide range of stand and site conditions, but cannot compete with dense shrubs and undergrowth (Hansen et al. 1974). The success of coniferous reproduction is dependent chiefly upon the absence of intense competition from subordinate vegetation (Shirley 1945). Because white pine is able to tolerate partial shade it can survive under a canopy of aspen-birch. However, light levels are too low under maple groves.

White pine regeneration should not be attempted on sites where Ribes species are present because ribes is the alternate host for white pine blister rust. Ribes eradication has been discounted as a practical means of controlling the spread of infection (Anderson 1973). In some areas of the high hazard zone for blister rust infection, which includes Itasca State Park, long-distance dissemination can occur. White pine regeneration should not be attempted on these sites either.

White pine should not be planted in small openings in the forest canopy because canopy openings with a diameter less than the height of the surrounding trees create ideal conditions for blister rust infection. Therefore, a closed canopy is an important aspect of site selection for white pine regeneration in high-hazard areas (French 1992). Aspen, birch and other light crowned species are good choices for overstory to reduce the risk of both rust and white pine weevil (Robbins 1984). Conditions are warmer and drier at night under a canopy and, therefore, less conducive to rust infection. Daytime temperatures are cooler, and thinner bark of terminal shoots of white pine growing in the shade of an overstory discourages attacks by the weevil.

Fire History

While white pine will reproduce readily after a light burn, repeated fires will exterminate it (Grant 1929) because white pine seedlings and young trees are not fire resistant. A repeating cycling sequence of catastrophic fires with intervening light surface fires can lead to long-term dominance by white pine for several thousand years. White pine is most abundant with a period of 150-300 years between catastrophic fires (Frelich 1992).

DIRECT OR NATURAL SEEDING

Direct seeding success has been limited almost exclusively to jack pine and oaks, according to Shirley (1937). White pine grows slowly in the juvenile stage and competing vegetation tends to crowd the seedlings out unless one or more weedings are performed. If white pine regeneration is to be attempted by direct seeding, the seed should be sown in the fall. This will provide the seeds with low temperature stratification over the winter, which induces prompt germination during the first warm days of spring. This is important for white pine because it germinates irregularly without moist, low temperature stratification.

White pine seedlings that are less than 30 days old are susceptible to serious heat injury and death on light sand or loamy soils because the soil-surface can reach and maintain lethal temperatures for prolonged periods of time. The presence of abundant surface-soil moisture has a large influence on soil surface temperatures on light, sandy soils. By selecting sites with soils that have a high water-retaining capacity or sandy open sites with a shallow water table (within 4 feet of the surface), lethal temperatures can be avoided and direct seeding success can be enhanced (Stoeckeler and Limstrom 1942). Seeding in autumn or early spring or special pretreatment to stimulate early germination will also help to reduce the threat of heat injury to young seedlings.

Natural seeding can be enhanced by the silvicultural method of shelterwood cutting. This method, when used properly, ensures that an adequate source of seed and partial shade are available during the initial stages of establishment and provides full sunlight later when it is needed for seedling growth and survival (Smith 1951). Clearcutting and seed-tree methods do not provide the seed nor the protection essential for seedling establishment and survival. A discussion of the shelterwood method procedures will be included under the heading of site preparation.

Seed Production and Dispersal

Like red pine, good white pine seed production is irregular and infrequent. This irregularity, coupled with the low viability of soil stored white pine seed (Thomas and Wein 1985b), compromises natural regeneration. If seedbed preparation does not coincide with a good seed year, successful regeneration is unlikely.

Good seed production occurs every 3-5 years, with little seed produced in most intervening years (Fowells 1965b). Most seed is dispersed within the month following cone maturity, which occurs in August and September (Wendel and Smith 1990). Seed is dispersed as far as 200 feet within a white pine stand and more than 700 feet in the open.

Seed production usually begins when white pines are 20-30 years old. Widely spaced dominant trees with full crowns produce the most seeds per cone (Wendel and Smith 1990). Furthermore, intermediate density stands produce far more viable seeds per hectare in a good seed year than high or low density stands.

Seedbed Requirements

White pine is more adapted to thick humus than the other pines and does not need bare mineral soil for germination and establishment (Ahlgren 1974 and 1976). According to Kotar (1992), white pine does not require soil scarification except where a thick mat of needle litter has developed.

The seedbed conditions that are necessary for germination and early survival of white pine differ depending upon whether the seedbed is partially shaded or is under full sun. Thomas and Wein (1985a) found that white pine needed shelter for successful establishment of seedlings on a drier, sandy loam site but not on a wetter, clay-sand site. The variable influence of seedbed conditions is confined almost entirely to areas exposed to direct sunlight and is due to differences in the efficiency of different seedbed materials to dissipate heat (Smith 1951). Under full sunlight, moist mineral soil, polytrichum moss or a short grass cover of light to medium density are considered to be favorable seedbeds. Dry mineral soil, pine litter, lichen and very thin or thick grass covers are unfavorable (Fowells 1965b).

If the seedbed is shaded, the type of seedbed cover does not have as much impact on seedling survival. But, at least 20% of full sunlight is required to keep seedlings alive (Wendel and Smith 1990). According to Smith (1951), treatment of continuously shaded litter to expose mineral soil serves no practical purpose because it does not improve germination and survival of white pine seedlings.

Polytrichum moss is the most uniformly favorable seedbed because it provides a good medium for white pine seed germination and protects the seedlings from microclimatic extremes, but it rarely competes with them. The moss receives most of its moisture directly from the atmosphere so its roots do not compete actively with the seedlings for water and nutrients in the soil (Smith 1951).

Smith (1951) noted that the surface of white pine litter can attain lethal temperatures in 10-25 minutes of exposure to direct sunlight, so even if seeds germinate, the seedlings are killed by heat injury. Since root penetration is not a problem through pine litter, this type of seedbed is good if protected from direct sunlight. Regeneration conditions on pine litter are best where the side-shade of trees to the south cuts off direct sunlight but does not prevent diffuse radiation from above.

Lichen seedbeds are only favorable if they are in shaded sites. On insolated areas, lichen seedbeds are inherently dry, so there would be no advantage to removing lichens and exposing the mineral soil to attempt white pine regeneration. Such sites would benefit more from thinly scattered slash. Woody debris, such as dead branches, thinly scattered over the surface of insolated litter provides beneficial shade and enhances seedling survival. Dense piles of fresh pine slash should be avoided, however, because newly germinated seedlings suffer damping-off underneath them (Smith 1951).

A ground cover of false lily-of-the-valley provides a favorable seedbed, providing some shade during the early period when microclimatic conditions are critical, but without towering over the seedlings and blocking out sunlight when it is needed later. Hardwood brush also provides the shade that is conducive to germination and early survival of white pine seedlings, but is too dense for subsequent development (Smith 1951). Some type of release from the competing brush would be necessary for white pine to survive on such sites.

The use of small cups as seed shelters have been effective in markedly increasing stocking rates in Ontario's white pine forests by improving the microclimate around the germinating seeds. In a study by Pinto (1992) only 34% of bare seeded spots were stocked after two growing seasons compared to 85% of the sheltered spots.

Site Preparation

Because white pine seedlings can germinate and survive on both disturbed and undisturbed litter layers (Wendel and Smith 1990), fire is not necessary for seedbed preparation. In fact some studies have shown that germination and growth have been poorer on burned soil (Ahlgren and Ahlgren 1960). Tryon (1948) found germination of white pine seed to be decreased in soil where charcoal had been added, and Perry (1935) found that growth of red and white pine was better on unburned soil. Scarification can be used in place of fire, as a corrective measure, on those sites where the seedbed conditions are in need of disturbance (McQuilkin 1959).

Although white pine is able to regenerate successfully under an overstory canopy, excessive brush in the understory is a deterrent to white pine seedling establishment (Hansen 1956). The use of herbicides has been used to eliminate and control competing vegetation on sites where regeneration is to be attempted. The use of 2,4-D to control brush in a white pine regeneration plot in Itasca State Park resulted in a 230% increase in white pine seedlings on sprayed plots with no increase in seedlings on the unsprayed plots during the same period (unknown 1952). One time spraying did not eliminate the brush completely, so repeated treatments were necessary throughout the period of seedling establishment to control competition. Monuron, a non-selective phytotoxic chemical, has been reported by Hansen and Johnson (1957) to be effective in stimulating the initial establishment of white pine by eliminating competing vegetation. However, monuron has long-lasting residual toxicity in some soils, and the authors of the study cuationed that it was unknown what impact the chemical would have on later survival of the white pine seedlings. In treatments using 32 pounds and 48 pounds of monuron per acre, aspen was killed within about 10 feet of the plot boundaries. The 48 pound treatment also killed all hazel brush on the plots.

As noted above, the shelterwood cutting system has been used successfully to encourage natural regeneration of white pine on a number of sites. Shelterwood cuttings allow for a maximum of diffuse radiation and a minimum of direct solar radiation to reach the forest floor. By controlling overstory density through shelterwood cuts, seedbed conditions are improved, seedlings are able to accumulate over the course of several years, seedlings are protected on hot, dry aspects, weevil attacks are reduced, and competition from herbaceous and hardwood vegetation is reduced (Wendel and Smith 1990). Several cuts spread over a number of years can be used, but white pine can usually be regenerated successfully with a two-cut shelterwood system.

Since immature white pine cones appear about one year before seeds are shed, shelterwood cuts can and should be timed to take advantage of good seed crops (Smith 1951). Smith further recommends a plan that involves cutting long, narrow strips along the east-west or northwest-southeast axes of a stand in order to take full advantage of the method.

In the Menominee Tribal Forest in Wisconsin, a two-step shelterwood management program is used which mimics a fire-succession sequence by artificially manipulating the balance of sunlight, competition and soil disturbance. In the first step the canopy is thinned, then the soil is scarified by tractors dragging heavy chains. In the second step, the overstory is removed gradually and carefully to release the young timber. While the seedlings are becoming established, competing vegetation is controlled by cutting and herbicide application. (Landis 1993, Heckman 1992). The initial cut thins the crown density to 70-80%. After the seedlings have become established, reduction of the crown density to 40-50% is timed to coincide with the period of rapid seedling height growth. Crown density is maintained at 40-50% until the new trees reach a diameter of about 5 inches, at which point the overstory can be removed totally or left intact depending upon its condition and expected damage to the young pines.

PLANTING SEEDLINGS

Planting seedlings is an option for white pine regeneration if no natural seed source is available. White pine does not thrive especially well in open plantings, but is sufficiently tolerant of the understory environment to be well-suited to underplanting and shelterwood management (Kotar 1992). According to Wendel and Smith (1990), white pine can be underplanted in hardwood stands, especially those comprised of oaks and hickories, with reasonable success. Kotar (1992) states that white pine can be established everywhere that stands of red oak, red maple or mixtures of these occur and can be introduced in any stand where blueberries or wintergreen grow but do not dominate the ground vegetation layer. Declining white birch stands in the Lake States may also be appropriate locations on which to attempt underplanting of white pine (Locey 1992). When white pine is planted in the open, close spacing of about 6 by 6 feet will increase the chances of obtaining an acceptable stand by rotation age. This spacing compensates for trees lost to weevils and encourages natural pruning of rust-susceptible lower branches (Robbins 1984). In a recent study of 17 and 8 white pine plantations in the Chippewa and Superior National Forests, respectively, Mielke et al. (unknown) found most to be in poor to fair condition due to repeated deer browsing and, in some, to blister rust.

White pine is intermediate in shade tolerance, with young seedlings developing and surviving in as little as 20% full sunlight (Stearns 1992). However, after establishment the seedlings become more shade intolerant and more light is required for adequate growth to occur (Shirley 1945). Maximum height growth will occur in as little as 45% full sunlight, but maximum wood production requires full sunlight (Logan 1966). Because of the changing light requirements of white pine as it ages, competition from other vegetation can become a serious problem, especially in underplanted sites. Geerinck et al. (1954) found that white pine planted under a mixed hardwood stand in the University of Maine Forest developed satisfactorily on sites where subsequent release from the overstory was heavy or complete. The best results were observed on the heavily released site, possibly because growth of hardwood sprouts was retarded by the light canopy that remained intact. Development was unsatisfactory on the lightly released and unreleased sites. Therefore, it was concluded that underplanting should not be attempted in young and vigorous hardwood stands unless early release cutting is planned.

As with red pine, the hole method is preferred over the slit method for planting white pine (Rudolf 1939). The slit method often results in cramped root systems, which leads to poor height growth. With the hole method, the roots are spread out when they are planted. Survival has been observed to be as much as 25% higher on plantations where the hole method was used than on plantations where the slit method was used.

The Rajala Lumber Company has had very high success in planting white pine seedlings under a thinned overstory of long-rotational overstory species in northern Minnesota (Rajala 1992). The following method is used. The overstory is thinned to 40-60% crown closure, which significantly reduces the risk of tip weevil damage. The site is raked to remove remaining slash from the thinning operation, to set back competing brush and other vegetation and to make hand planting easier. Seedlings may be planted the first spring following site preparation or a year later if chemical control of brush has been necessary. Seedlings are planted 800-1,000 per acre with a goal of 100-150 crop trees per acre 100 years later. In some cases, hand or chemical release from competing understory becomes necessary later. However, chemical release has shown signs of harm to seedlings that have been in the ground for only 1-2 years.

Paper bud caps applied in fall to the terminal buds of white pine seedlings have significantly reduced damage from deer browsing (Sanow and Barnacle 1992, J. Rajala, personal communication). The bud caps must be applied each fall until the seedlings have grown beyond the reach of deer, about 7 ft.

TREE MORTALITY/SURVIVAL

Competition From Other Vegetation

White pine can compete successfully against birch, but often loses out in competition with aspen, oak and maple (Wendel and Smith 1990), nor can it compete with dense shrubs and undergrowth. In the seedling stage, white pine is very susceptible to competition because its height growth is slow compared to associated species. Open-grown white pine trees are about 5 inches high when 3 years old, 12 inches high when 5 years old and 4.5 feet high after 8-10 years (Fowells 1965b). However, if the tree survives to the sapling stage, its ability to compete is greatly improved because its annual growth rate increases considerably. Between 10-20 years, the average annual height growth is16 inches and between 20-30 years it is 20 inches.

Surface fires and windthrows function as natural mechanisms to release white pine from overstory and understory competition, respectively (Frelich 1992). If such disturbances are unavailable, artificial release may be necessary in the form of cutting, herbicide treatment or prescribed fire. The use of herbicide spraying has been used successfully in Itasca State Park to release white pine from shrubs and undergrowth (Hansen, et al. 1974). Removal cutting of competing birch and maple in the Harvard Forest released young white pine and improved subsequent stand quality and health as compared to an unreleased control stand (Spaeth 1922). Mechanical removal alone was not found to effectively control competitive shrubs, aspen and white birch in Ontario's white pine forests (Pinto 1992). Aspen, birch and Rubus spp. increased markedly after mechanical removal and cut stems of shrubs were quickly replaced by sprouts and suckers. A combination of mechanical site preparation using a blade and herbicide treatment was much more effective.

Young white pine should be released from the overstory by removal cutting when release will most benefit the stand. Timing of release cutting should be based on the height of the white pine, the type of hardwoods present and the quality of the site, according to Spaeth (1922). If the white pine is too young when released from the overstory, a second removal cutting will be necessary. He recommends release cutting between the 10th and 25th year in the life of the stand for an average site in New England. Engle (1951) states that success in releasing suppressed white pine from oak and aspen overstories is dependent on the height of the pine at the time. The taller the pine, the better it will be able to compete with sprout growth. He recommends that white pine be at least 4-5 feet tall and preferably 6-8 feet tall before release is attempted. Finally, Wendel and Smith (1990) feel that the response to release from hardwoods depends primarily on how strong the competition has been and how long the pine has been in a subordinate position. They report that pines less than 30 years old with at least one third of their height in live crown respond well, but response declines proportionately with increasing age and decreasing crown length.

Impact of Deer and Other Animals

Porcupines, snowshoe hares and deer have potential for impact on white pine seedlings and saplings. Sauerman (1992) reports that in a study of 126 white pine stands throughout northern and southeastern Minnesota, 53% of stands and 23% of all trees examined had been damaged by deer browsing, with 70% of the damage occurring on trees in the northern region of the state. Damage was very high in 6-8 year old stands. Deer browsing is particularly problematic in Itasca State Park. The impact of deer browsing on white pine regeneration in Itasca State Park was demonstrated by a dramatic increase in seedlings over 4 years old, from 0 to 2,000 per acre, within 4 years after the 1945 deer herd reduction (Hansen 1967). In Wisconsin, the impact of deer browsing was noticeably lower on the Menominee Indian Reservation than on state forests, due to much lower deer densities. On the reservation, only 1 out of 10 seedlings was being damaged by deer, but on state forests it was estimated that only 2 out of 5 seedlings would reach the sapling stage (Swift 1948).

White pine is quite sensitive to deer browsing, becoming stunted and deformed even at low deer browse pressures. It is particularly damaged by high frequency browsing because most photosynthesis occurs at the needle tips of current annual growth (Steingraber 1989, Marshall et al. 1955). Measures to control deer browsing include repellents, protective coverings and fencing, which will be discussed in detail in the section on deer management.

Red and white pine are preferred over other conifers and hardwoods as winter food sources by porcupines in Itasca State Park (Anfang 1972b). Porcupine feeding can result in reduced quality or growth and possibly death of the tree. Once a porcupine finds a suitable tree, it will return to that tree repeatedly to feed. Porcupine feeding was observed by Anfang (1972b) to be most common on white pine with a diameter of 10-13 inches, on average. Most scarring on white pines was in the crowns of the trees.

Impact of Insects and Diseases

A total of 277 insects and 110 diseases are known to attack white pine. The three most significant are the white pine weevil, white pine blister rust, and *Armillaria mellea* (Wendel and Smith 1990).

The white pine weevil kills the terminal shoot and sometimes the last 2-3 years of growth, which results in crooked boles and loss of stem length. The standard practice to control weevils is to grow white pine under an overstory because shade reduces weevil attacks (Jones 1992b). Sauerman (1992) documented weevil damage in 23% of white pine stands and 9% of all trees he examined in a study of 126 white pine stands in northern and southeastern Minnesota, but noted that 83% of the underplanted stands examined had no incidence of weevil damage. Weevil damage was extensive on the one stand he examined in Hubbard County, which is close to the Itasca State Park area.

Armillaria is a fungus that radiates and girdles pines at the root collar and causes resinosus. It lives in hardwood stumps and radiates up to 30 feet, destroying white pine seedlings and saplings on contact (Wendel and Smith 1990).

White pine trees are susceptible to white pine blister rust from the seedling stage through maturity. Sauerman (1992) found white pine blister rust in 51% of stands and 5% of all trees examined in his study of white pine stands in northern and southeastern Minnesota. However, 92% of underplanted stands had no incidence of rust. Hansen (1967) and Orke (1966) found that blister rust was affecting white pine seedlings in Itasca State Park. Willard (1936) reports that blister rust can compromise white pine regeneration. However, Jones (1992b) states that data on the impact of blister rust are not definitive, and that it is unknown if blister rust is just a thinning mechanism or if it will eventually lead to total stand elimination.

Infection of white pine blister rust is favored by extended periods of moderate temperature (below 67 degrees F.) and the presence of free moisture on the needle surfaces (usually dew) during late summer and early fall when teliospores form on Ribes leaves. Small differences in temperature or duration of favorable temperature and moisture can greatly influence prevalence of infection. According to Anderson (1973), these small differences have led to the designation of low to high risk areas for blister rust infection. Parts of northern Minnesota, possibly including Itasca State Park, are considered to be high hazard areas.

Management practices that help to reduce the impact of blister rust include microsite evaluations to avoid planting in high risk areas, underplanting, avoiding planting in small openings, pruning, and Ribes eradication (Jones 1992b). The most effective technique to control the spread of blister rust is to select low hazard sites based on local microclimate (Anderson 1973), as discussed in the section above on site selection.

Pruning to remove cankers from infected trees has produced excellent results, and can be pathological, where only diseased limbs are removed, or silvicultural, where all lower limbs and those with cankers in the upper five whorls are removed, as defined by Stewart (1957). However, pathological pruning is described by Robbins (1984) as removing branches from the lower half of the crown beginning three years after planting and continuing periodically until the lower nine feet of the bole is free of branches. Therefore, there seems to be some discrepancy about the definition of pathological and silvicultural pruning in the literature. Guidelines have been developed for evaluating potential sites for pathological pruning by Nicholls and Anderson (1977) and have been recommended by Mielke et al. (unknown). Under these guidelines, acceptable annual rates of infection are 1% on sites with 200-299 white pine per acre, 2% on sites with 300-399 white pine per acre and 3% on sites with 400-499 per acre. Pathological pruning is appropriate on sites where the rate of infection exceeds these levels.

According to Stewart (1957) the silvicultural pruning method has been more effective, but there are other considerations that may make this method impractical. To be most effective, the original pruning should be followed up with a second pruning to extend pruning height to 17 feet, and Ribes should be removed from the area. It is recommended that this method only be considered for well-stocked stands where removal of Ribes is economically feasible. Three methods of canker removal that have been successful include removing the entire branch when the canker margin is at least 6 inches from the trunk, removal of the branch and excision of the bark around the branch stub when the canker is nearer the trunk, and removal of the top of the tree below the canker margin where the canker is on the upper main stem.

Ribes eradication can be difficult and impractical to accomplish as a measure to control the spread of blister rust. Ribes species can reproduce by seeds, which remain dormant in the soil for long periods of time until the right environmental factors break the resistance of their hard seed coats (Stewart 1957). Recent burns seem to be a factor in breaking that resistance. Therefore, fire can often increase the incidence of disease by producing thick stands of the host plant. A second burn or other eradication method is necessary for effective control (Ahlgren and Ahlgren 1960). Ribes eradication may be useful where short distance (less than 100 feet) spread of spores is important, as is the case in Hazard Zone 3, but is ineffective where long distance spread is common, as is the case in most of Hazard Zone 4. Distances that spores spread are based on an area's characteristic pattern of nighttime air currents (Robbins 1984).

Fire Effects

Old white pine trees can survive fire, however, seedlings and saplings are easily killed. The bark on exposed roots and stems of second growth white pine stands is thin and fire resistance is low. On older trees the bark is thicker and moderately fire resistant (Wendel and Smith 1990). Therefore, a fire frequency of less than 10 years may result in elimination of white pine regeneration. According to Frelich (1992), white pine is most abundant with a period of 150-300 years between catastrophic fires.

Johnson (1992) found that the lethal temperature for cambium is 60 °C and that white pine 40 cm. in diameter could survive for about 12-13 minutes in a fire. Kayll (1968) tested heat tolerance in seedlings, but suggests that his results may also be applicable to the crowns of mature trees because they are similar in many ways. He found that physiologically active seedlings could withstand 60-78 °C heat applied to their stems for 1 minute, but that dormant ones could tolerate between 93-108 °C heat for the same length of time. Therefore, he concludes that heat damage to white pine may be minimized during prescribed burning if it is done either in early spring or late fall while the trees are dormant. Prescribed burning experiments conducted by Van Wagner (1965) revealed that first year pine mortality after fire was due solely to severe crown damage and that tree size was a minor factor compared with the proportion of the crown that was killed. The dead trees in his study ranged from 2-12 inches d.b.h.

Length of Life

Estimates of the maximum average life span of white pine ranges from 450 to well over 500 years (Wendel and Smith 1990 and Stearns 1992).

JACK PINE

JACK PINE STANDS IN ITASCA STATE PARK

Jack pine was found by Lee (1924) to occupy sandy soils in the Itasca region. These infertile soils often contain ferrous compounds. Soil conditions improve slowly on the coarse, loose soils characteristic of jack pine stands, due to constant leaching of organic materials and minerals. Due to these unfavorable conditions, other tree species have had difficulty invading, and jack pine has been able to establish an edaphic climax.

In a survey of pine types on tracts east of Lake Itasca, Cheyney (unk.) found jack pine on sandy soils, but noted that these soils differed from the typical jack pine type because they contained a slight trace of clay. The subsoil was a very gravelly clay.

Hansen and Brown (1950) characterized jack pine stands they observed in Itasca State Park as virtually brush-free, supporting fine crops of pine seedlings, especially white and jack. Kurmis and Hansen (1969) found that jack pine seedlings were limited to nutrient-poor sites in Itasca State Park, such as the jack pine-bearberry types. However, they noted that competition from shrubs and undergrowth was a serious problem for jack pine regeneration, despite the harsh conditions found on these sites.

According to Kell (1938) the soils of jack pine and red pine stands in Itasca State Park resemble each other more closely in water retaining capacity than either of them resemble the soils of white pine stands.

JACK PINE STANDS IN GENERAL / OTHER AREAS

Jack pine is found associated with other tree species in the Boundary Waters Canoe Area depending on soil type, aspect and slope. Ohmann and Ream (1971) characterized these associations as follows. The jack pine-oak community type is found on bald rock ridges and rock outcrops, usually situated on ridgetops, upper slopes with an average slope of 10%, and sometimes on midslopes with as much slope as 24%. Soils are generally less than 20 inches and sometimes only 6 inches above bedrock. This community type is dominated by jack pine and is characterized by recent disturbance by fire. The jack pine-fir community type is also dominated by jack pine and is characterized by recent disturbance by fire, but soil depth is usually from 20-40 inches above bedrock, bedrock outcrops are not present, and the usual location is on mid to lower, north to northeast facing slopes.

The jack pine-black spruce community type is dominated by jack pine in the canopy, but black spruce is taking over due to a lack of recent fire disturbance. This community type is located on southerly and southwesterly facing slopes, farther away from water bodies than other jack pine types. It has low water retention capacity in the B soil horizon, and also has low pH and low levels of calcium, potassium and phosphorous in the B soil horizon.

Jack pine is also found associated with black spruce in the black spruce-jack pine community type. In such stands, jack pine is dominant in the canopy but black spruce is the most common canopy species. Unlike the jack pine-black spruce community type, fire disturbance has been recent and initial composition after fire consists of both jack pine and black spruce. Stands are located on mid to lower southerly or westerly slopes with soil depths between 18-24 inches above bedrock, and the forest floor is covered with a thick layer of moss that inhibits shrubs and herbaceous growth.

In Michigan, Graham, et al. (1963) discovered mixed stands of jack pine and aspen on sandy, outwash plains. They expected the jack pine to outlive the aspen on these sites and take over the stands. However, they also expected fire or some other natural disturbance to eventually kill the jack pine, allowing remaining scattered aspen to reproduce by suckering and take over the stand.

JACK PINE REGENERATION

Fire is an important aspect of jack pine regeneration because the serotinous pine cones require heat to open and disperse their seeds (Cayford and McRae 1983). However, good regeneration does not necessarily follow fire, unless conditions for germination and early survival are favorable. According to Rudolph and Laidly (1990), optimum conditions for germination and survival of jack pine are provided on mineral soil and burned seedbeds where competition from other vegetation is not severe, where the water table is high and where there is some shade. Other factors that affect jack pine regeneration include fire intensity, weather conditions after fire, stand density, seed supply and site characteristics (Cayford 1971). Because jack pine is highly flammable, fire can be difficult to manage as a reproduction tool (Eyre 1938). If fire is too intense, it can destroy jack pine seeds in the cone.

The quick flush of herb growth that often occurs after fire does not impede jack pine seedling establishment because the seedlings grow rapidly above the other vegetation (Ahlgren 1976). For example, under good growing conditions seedlings reach breast height in 4-6 years and a height of 20 feet in about 18 years (Eyre and LeBarron 1944). The post fire herb growth can actually enhance regeneration success by providing the moist, cool micro-environment necessary for early jack pine seedling growth and survival.

Fire may also be responsible for stimulating improved germination of jackpine seedlings. Ahlgren (1959a , 1960) found that seed from scorched jack pine cones produced as much as 50% better and had earlier germination than seed from unburned trees. Furthermore, cone production occurred earlier and was more abundant on jack pines that reproduced on burned over sites than on nearby plantations.

Clearcutting, seed-tree cutting and shelterwood cutting are all effective harvesting systems for jack pine management and subsequent regeneration (Benzie 1973b). Cayford (1971) reports that successful jack pine regeneration has been obtained by burning clearcut stands and broadcast seeding and by burning in conjunction with the reservation of seed trees during logging. In partially cut jack pine stands, regeneration can occur after fire if an adequate seed source is present. Ahlgren (1959a and 1959b) found that as few as 10 dominant jack pine (12 inches d.b.h.) per acre resulted in 15,000 to 20,000 seedlings per acre on good seedbeds. In Michigan, satisfactory regeneration was obtained by retaining 12-50 seed trees per acre.

Jack pine can also be successfully regenerated without fire if the soil is mechanically disturbed to expose the mineral soil and jack pine slash is scattered properly on the ground (Eyre

1938). Exposure to the heat of the sun has been demonstrated to be adequate to open jack pine cones if they are lying close to the ground where temperatures get high enough to break the serotinous seal. The use of scattered slash will be discussed more thoroughly below.

SITE SELECTION

Soil Properties

Although jack pine does not have very particular soil requirements, it is usually found on poor soils, such as dry, sandy soils (Grant 1929). In Minnesota, it is found on soils such as Menahga sand, Cass Lake fine sand and Kinghurst loamy sand (Eyre and LeBarron 1944). Characteristic sites include dry sand plains developed on glacial outwash, morainic, aeolin and beach deposits (Cayford and McRae 1983). In Michigan's presettlement forests, jack pine occupied the excessively drained, coarser textured soils on old outwash channels and plains (Whitney 1986). Jack pine is sometimes considered to be an edaphic climax on dry, sandy Grayling, Rubicon, Plainfield, Vilas and Menahga soils because successional changes on these poor sites are extremely slow (Benzie 1977b).

Jack pine grows best on well-drained loamy sands where the mid-summer water table is from 4-6 feet below the surface (Rudolph and Laidly 1990). However, it rarely becomes dominant on better soils because it is shade intolerant and cannot compete with the other tree species found on these higher quality sites (Grant 1924).

On cutover jack pine areas in Itasca State Park, Buckman (1953) found that the extent of sorting in soils is a determining factor on whether regeneration will be primarily pine or aspen. Jack pine is expected to be the primary constituent on partially sorted glacial soils, and aspen is expected to be the primary constituent on unsorted glacial soils. Kurmis (1985) observed that jack-red pine forest types are found on excessively to well-drained, loamy, coarse sands to gravelly loams in Itasca State Park.

Topography

The literature review did not reveal much in the way of specific land features, slope, aspect, etc. that favored jack pine regeneration. However, Burgess and Methven (1977) found that well-stocked even aged jack pine stands were found on relatively level ground following fires of constant high intensity that had killed the existing stand. Patchy, multi-aged jack pine stands resulted from fires of low to moderate intensity on uneven topography. In the BWCA, jack pine was found in areas where fire was most frequent and intense (Heinselman 1973). Such areas include large upland ridges and ridge complexes, distant from or west of natural firebreaks.

Whether seeding or planting to regenerated jack pine, success is enhanced on sites that have a shallow water table because soil moisture is greater and more constant and soil temperatures are more likely to be held below lethal levels. Small jack pine seedlings (less than 30 days old) are susceptible to heat injury and death when soil surface temperatures remain higher than 120 °F between 10:00 a.m. and 4:00 p.m. (Stoeckeler and Limstrom 1942). In upland areas, lethal temperatures are commonly reached and maintained for several hours during the day, thus placing young seedlings at considerable risk. According to Stoeckeler and Limstrom (1942), plantation survival is enhanced where the water table is from 3-6 feet below the surface, and direct seeding is enhanced on light, sandy soils with a permanent water table within 5 feet of the surface. Northern exposures can also produce moist and favorable conditions for the survival of young jack pine seedlings (Shirley 1937).

Vegetation Present

Jack pine is the least tolerant of the pines, so care must be exercised when selecting a regeneration site to avoid sites where other vegetation will be too competitive. Direct seeding and plantation efforts have been complete failures when no effort has been made to thin the overstory, eliminate competition from shrubby and herbaceous understory and remove hardwood leaves in the spring (Shirley 1937). Areas of sandy soil covered with a low turf of blueberry, sweetfern and other low shrubs with or without scattered clumps of scrub oak, hardwood burns with grass sod and sumac, or practically barren sites are recommended for direct seeding of jack pine because they are comparatively free of other vegetation after soil preparation (Shirley 1937).

In the Lake States, the pines are only occasionally able to take over aspen areas because competition for light, crown space, soil moisture, and nutrients can be a serious problem

(Heinselman 1954). Aspen does not act as a nurse crop to favor establishment or growth of pine seedlings, but rather smothers and suppresses them. Where aspen is dense enough to form a stand, pines are present only as seedlings the same age as the aspen or as small seedlings that live for a few years and die (Shirley 1941). Conifers are usually more productive than aspen on poorer sites, so conversion to jack pine may be appropriate on such locations (Perala 1977). Sites where aspen fails to reach pulpwood size before becoming decadent are good candidates for conversion because aspen and undergrowth are least aggressive on these sites and are more readily displaced (Shirley 1937).

The presence of certain plant species may inhibit or stimulate jack pine seed germination. Brown (1967) conducted germination experiments on jack pine seeds in the laboratory while in the presence of extracts from various plant species. Nine plant species significantly inhibited germination in the lab and of those *Prunus pumila, Solidago juncea* and *Gaultheria procumbens* showed definite inhibition in field tests. Germination was sometimes stimulated by other plant extracts. In field studies, the presence of *Pinus resinosa, Cornus canadensis* and *Pteridium aquilinum* enhanced germination the most.

Fire History

Although fire is an important factor in jack pine regeneration, a fire interval that is too short can be detrimental. A fire during the first few years of seedling establishment may kill all seedlings and reduce the area to brush or grass. A fire after the seedlings have started to produce cones may do nothing more than set the stand back a few years (Eyre and LeBarron 1944). Jack pine is favored by fire cycles of less than 100 years (Frelich 1992). Historically, the jack pine stand type in the BWCA was subject to short return interval, crown fires (every 25-100 years) or long return interval, crown fires (every 100-300 years) (Hendee et al. 1978).

The season in which fire usually occurs may have an impact on the success of jack pine regeneration, as well. Ohmann and Grigal (1981) observed that jack pine stands where wildfire occurred in the summer regenerated primarily to jack pine, but in stands where wildfire occurred in the spring regeneration was mainly vegetative from quaking aspen. This difference was because the spring fire occurred when the forest floor was still cool and moist so there were few areas where the humus and litter were completely removed. Whereas, the summer fire removed the litter and humus almost everywhere, creating a more favorable jack pine seedbed.

DIRECT OR NATURAL SEEDING

There appears to be some disagreement between sources as to the viability of using direct seeding as a method to regenerate jack pine. Benzie (1977b) states that jack pine is one of the most successful species for direct seeding. He does, however, point out that poor results will occur on droughty soils if precipitation is lacking for more than a few days during germination or for more than a week during early seedling establishment. Shirley (1937) states that direct seeding success has been limited almost exclusively to jack pine and oaks, but does not recommend direct seeding as an alternative to planting. He claims that seeding is unsuited to areas where the rodent population is too dense or in areas supporting dense competing vegetation. He recommends using seeding only as a supplement to planting, and remarks that, except for swamps or particularly rocky sites, no area can be established to conifers by direct seeding that cannot be planted successfully.

The major problems related to direct seeding seem to be predation on seeds by rodents, the threat of competing vegetation taking over the site, heat injury to seedlings, and lack of moisture during the critical period of establishment. Since jack pine seeds are small, they escape complete destruction by rodents, but certain measures may be necessary to ensure adequate germination success. Ahlgren (1970) recommends that seeding be timed to avoid high activity periods of rodents, such as in the late fall. Benzie (1977b) recommends that seed be coated with bird and rodent repellents prior to sowing. Stoeckeler and Sump (1940) found that in the Nicolet National Forest of northeastern Wisconsin, seeding too early in spring (on April 9) delayed germination and left the seed vulnerable to predation for too long. They recommend that seed be sowed when the period between seeding and germination will be as short as possible. Good results were achieved when they sowed seed prior to May 7th but after April 9th. According to

Eyre and LeBarron (1944) jack pine seed will germinate rapidly under favorable moisture conditions whenever the10-day mean maximum air temperature is 65 degrees F. or higher.

Heat injury and lack of moisture during the early establishment period can be avoided by selecting seeding sites that have shallow water tables (between 2-5 feet below the surface) (Stoeckeler and Sump 1940). Such sites have higher soil moisture levels which can reduce surface soil temperatures. According to Stoeckeler and Sump, these sites usually occur in the Lake States in small units of 20-200 acres interspersed with higher-elevation land of extensive acreage. In upland areas, lethal temperatures are commonly reached and are maintained for several hours, resulting in considerable heat damage and mortality of new seedlings (Stoeckeler and Limstrom 1942). Sowing in the fall or early spring can also help to reduce heat injury by allowing early spring germination (Eyre and LeBarron 1944).

The problem of competing vegetation should be dealt with by proper site preparation and avoidance of areas where dense vegetation may become an ongoing problem. Eyre and LeBarron (1944) recommend using newly cut-over areas or fresh burns rather than deforested areas of long standing for direct seeding. On fresh burns, there is less plant competition and less danger of the seeds being eaten by rodents.

The recommended amount of seed that should be sown per acre to give best results ranges in the literature from 3 ounces (Benzie 1977b) to 5-6 ounces (Ahlgren 1970). Shirley (1937) recommends sowing seed with a mechanical drill in plowed furrows, and Stoeckeler and Sump (1940) recommend covering the seed with a thin layer of soil for best results. Stratification was not found to increase germination of jack pine seed, so such pretreatment is not necessary (Stoeckeler and Sump 1940).

Because jack pine seed is stored in serotinous cones, natural seeding is likely to occur only after fire. The serotinous cones require fire, or some other heat source, to break the seal and release their seeds. Dissemination of seed from live stands of jack pine is very light in the absence of fire, and insufficient for adequate regeneration (Eyre 1938). Therefore, jack pine is not dependable as a seed tree (Eyre and LeBarron 1944). Seed fall from felled trees and those killed by girdling, insect damage or drought is also very light. Therefore, these trees are not dependable seed sources for jack pine regeneration either (LeBarron and Eyre 1939).

Seed Production and Dispersal

Jack pine begins producing seed at an early age, as young as 3-5 years old, according to Cayford and McRae (1983) and Ahlgren (1976). Significant seed production is attained by age 10, and possibly as early as 6-8 years of age, but production is best on 40-50 year old trees (Benzie 1977b). Seed production varies from year to year, but some seed is usually produced every year (Rudolph and Laidly 1990). Good seed crops are produced every 2-4 years (Benzie 1973b).

The effective range of seed dissemination is about 2 tree heights, but is low beyond 1 tree height (Rudolph and Laidly 1990). Watson (1937) concluded that about 75 trees well-distributed over an acre, with a crown spread of 1/100 of an acre each (about a 12 foot radius), are required to seed an acre following a fire.

Seed can be successfully dispersed from serotinous cones without the use of fire by scattering cone-bearing slash over bared mineral soil. This technique was used to successfully regenerate jack pine in northern Minnesota and the Huron National Forest in lower Michigan (Rudolf 1946). Slash should be uniformly scattered close to the ground, because prompt and complete opening of cones in slash is assured only if they are within inches of the ground where temperatures will reach 140 degrees or higher (Eyre and LeBarron 1944). Within a space of only 4-5 inches above the surface of the ground the air temperature diminishes by more than 30 degrees, so proper placement of slash is imperative. If slash is placed in piles or windrows, only the cones around the edges and at the top will release their seed.

Slash should be left in place for 2-3 years to attain the greatest success of seed dispersal (LeBarron and Eyre 1939). Early seedling establishment will be enhanced by the shade provided by slash, but accumulation of large armounts of slash should be avoided. Slash accumulation can interfere with later seedling establishment and can present a fire hazard during the early years when the seedlings are vulnerable (Benzie 1977b).

Ground scarification, using an Athens type disk, produces an adequate seedbed for jack pine regeneration from scattered slash. Satisfactory stocking can be obtained when 60% or more of the mineral soil is exposed (Zehngraff 1943). Seasonal timing is important to the success of this process. Zehngraff (1943) recommends that scarification, followed by slash distribution, should be done in early spring prior to May 15, or in late fall after all possibility of fall germination has passed. Germination after September 1 may result in heavy winter killing. Best results have been obtained on 70-80 year old well-stocked stands with even distribution of cones. Ten to fifteen good cones per mil-acre are required to produce one good seedling.

Regeneration following slash fires in clear-cut jack pine stands has usually been inadequate because of the destruction of cones in the slash (Cayford 1971). Fires burning through such areas consume the unopened cones in the slash, and since the area has been cleared of trees, there is no other seed source available.

Seedbed Requirements

The type of seedbed affects germination success and early survival of jack pine seedlings. Rouse (1986a) found that jack pine seeds germinate best on mineral soil or soil with less than 0.2 inch of organic matter. Chrosciewicz (1974) reported that in central Ontario, very high quality seedbed conditions were found on moderately dry, upland, clearcut sites that had less than 0.2 inches of residual humus after burning. High quality conditions were found on seedbeds with residual humus between 0.2-0.5 inches, and humus thicker than 0.5 inches provided only moderate to low seedbed quality. Jack pine seedling establishment was found by Ahlgren (1976) to be satisfactory on seedbeds where the humus was reduced to 1 inch or less. He also noted in 1959 that in the Superior National Forest young seedling mortality was high on sites where a dry organic layer of 3 or more inches remained after fire. Rudolph and Laidly (1990) found that in northeastern Minnesota, germination under clearcut and partially cut jack pine stands averaged 60% on mineral soil, 49% on burned duff, 47% on scarified and shaded duff and 17% on undisturbed duff.

Poor germination on litter and humus is caused by poor moisture conditions (Rudolph and Laidly 1990). Some shade, such as that from standing dead jack pines, favors germination by allowing retention of moisture for a longer period of time (Rouse 1986a). Seedbeds of mixed humus and mineral soil can also cause problems for young seedlings, in the form of increased competition, due to the roots and seeds of other plant species that they contain (Benzie 1977b).

Site Preparation

The two major objectives of site preparation should be to 1) permit the seed to make contact with mineral soil where moisture conditions are more stable than in the humus layers, and 2) to eliminate or sufficiently reduce the existing vegetation so that tree seedlings have a better chance to compete for moisture, nutrients and light (Benzie 1968). Therefore, site preparation for direct or natural seedling of jack pine should involve exposing mineral soil seedbeds, controlling shrubs and other competition, and treating slash to reduce the fire hazard and hindrance to regeneration (Benzie 1977b). The objectives of site preparation can be met by using fire or mechanical equipment.

Prescribed burning has been used successfully to prepare sites for jack pine regeneration when direct seeding or natural seeding from seed trees is used. Burning can be a problem when used in conjunction with scattered slash as the source of seed because the cones and seeds may be destroyed in the process (Cayford 1971). The major drawbacks to using prescribed burning to prepare seedbeds are the inflexibility of timing of the fire and the risk of fire getting out of control.

Ahlgren (1970) reports that back fires give good results in terms of humus reduction and seedbed preparation because they spread slowly and create prolonged high temperatures. It is also possible, as was observed in his study, that back fires can stimulate cone opening on seed trees and can retard shrub competition for several years post fire. Ahlgren cites a combination of high fire danger and a drought index of 10 as the best conditions for prescribed burning to remove humus. Cayford (1971), on the other hand, recommends head fires as the most successful method of burning. He claims that head fires rapidly dispose of slash, open cones in seed trees and are especially valuable when fuels are discontinuous or sparse. He cautions, however, that head fires are more difficult to control than back fires and recommends they be started only after burning a safety strip on the extreme downwind side of the treatment area. Benzie (1977b) points out that fires must be hot enough to consume most of the humus and leave bare mineral soil if they are to successfully prepare the site for regeneration. Therefore, he recommends that prescribed burning be limited to areas that have sufficient fuels to produce a hot fire.

Mechanical equipment can be used to successfully prepare a site for jack pine regeneration when the site is to be direct seeded or seeded by scattering cone bearing slash. Various methods have been recommended for exposing mineral soil, from disking and heavy scalping to plowing furrows. The method used may depend in part on the type of soil present.

On dry soils, such as Grayling sands, deep scarification with an Athens disk was found to be more effective than removing only small patches of surface organic material with a field cultivator (Cooley 1972). Disk furrows collected more moisture and retained it longer and checked reinvasion by competing vegetation during the first season. Disking was even found to improve seedling growth over those seedlings grown in undisturbed sites. Shirley (1937) reports that disking is effective in exposing mineral soil on sandy areas, but seems to stimulate growth of competing vegetation. He maintains that the most satisfactory methods of soil preparation have been large-sized scalps that completely remove duff or sod and plowed furrows.

According to Benzie (1968), disking or scalping on cut-over jack pine sites prior to seeding resulted in adequately stocked stands three years after treatment. Unprepared, logged sites were poorly stocked. Disking after logging exposed mineral soil on 48% of the area; whereas, disking before logging exposed 38% of the mineral soil. Zehngraff (1943) also reported that satisfactory regeneration resulted on clearcut sites in the Chippewa National Forest after scarification with an Athen's disk and scattering of cone-bearing slash. Cross disking, once in either direction, was sufficient to produce a good seedbed. He, however, found that 60% or more of the mineral soil must be exposed in order to produce good stocking.

Disking can be cone either before or after logging according to Zehngraff (1943). Each method has its advantages. If disking is done after logging, the process is cheaper, the area can be more completely covered and the danger of competition from herbaceous species is lessened. If disking is done before logging, there is no problem with cones being buried and lost, and there is no need to pile or bunch slash for storage. If scarification is done too long before logging, competition from herbaceous vegetation may necessitate a release operation within a few years.

In addition to exposing mineral soil, mechanical equipment can be used to remove shrubs and other competing vegetation. Light shrub cover can be controlled by full-tree skidding, hand cutting or scalping, or machine scalping with a furrowing plow (Benzie 1977b). Medium shrub cover may require disking or roller-chopping and heavy shrub cover may require bulldozing, shearing, rock raking, root raking or the use of herbicides.

PLANTING SEEDLINGS

Planting seedlings seems to be a reliable method of attempting jack pine regeneration and may actually be preferable to direct seeding. Shirley (1937) advises planting jack pine seedlings over direct seeding to regenerate jack pine, and has found that there is almost no site that can be direct seeded that cannot be planted successfully. Cayford and McRae (1983) have observed that plantations of jack pine seedlings survive drought better than direct seeded sites, which may be especially important on dry, sandy soils. Although jack pine is generally drought tolerant, heat is a major cause of mortality in jack pine plantations. Such losses can be cut down by using shade to reduce surface soil temperatures (Rudolf 1939).

Some form of site preparation is indicated in most situations to minimize mortality due to leaf smother and vegetative competition on jack pine plantations. Alm and Schantz-Hansen (1970) studied and compared jack pine tubeling survival and growth where 1) no site preparation occurred, where 2) the site was burned once in the spring of the year the seedlings were planted, where 3) the site was burned 3 and 1 year before planting and where 4) the site was cut and windrowed. Mortality was high on the first two site types. On the third type, vegetative competition was minimal, and planting conditions were optimal for jack pine survival. Jack pine seedling height growth was greatest on the fourth site type. Eyre and LeBarron (1944) found that the best method of preparing sites for planting is to furrow with a heavy plow.

Eyre and LeBarron (1944) also recommend spring planting over fall planting to minimize losses. The findings of Cayford and McRae (1983), that seedlings planted on areas that had been pre-burned had a higher survival rate if planted in spring than in fall, support that recommendation. By planting tubelings, Alm and Schantz-Hansen (1970) were able to outplant jack pine in Minnesota during the growing season. They had good success with seedlings planted between June and August, but cautioned that a cut-off date for tubeling planting should be early or mid-August.

Cramped root systems, where the bulk of the roots are found in a single plane can seriously compromise jack pine seedling growth and survival (Rudolf 1939). This problem can best be avoided by planting using the hole method, where the roots are spread out when planted, rather than using the slit method, where the roots are planted in a single plane. In addition to using the preferable planting method, greater success can be achieved by planting large age classes of stock (Stoeckeler and Limstrom 1942).

TREE MORTALITY/SURVIVAL

Competition from Other Vegetation

Jack pine has low tolerance for shade than red or white pine. Both Shirley (1945) and Ahlgren (1974) found that during germination, establishment and early growth, jack pine benefits from partial shade. But, Logan (1966) found that by age 5, jack pine requires full sunlight for maximum growth. The amount of sunlight available also affected the root systems in young jack pine, with drastic reductions noted in root systems development with diminishing light levels. Stallard (1929) reported that the rate of jack pine seedling growth was dependent on the amount of light available in xeric habitats. In the open, maximum annual growth was attained by the tenth year. But, in the shade where light values ranged from 6-20%, annual growth diminished after the first year until the seedlings perished. Average light values under thick stands of mature jack pine were below 16%, which is inadequate to support jack pine regeneration.

Because of the demands of young jack pine for considerable light, competing vegetation can present a major problem for regeneration efforts, and a conscious effort must be made to maintain favorable light conditions. Therefore, seedling release may be necessary between the third and fifth years (Benzie 1968). If jack pine reproduction has been too dense, thinning of the stand can provide additional release for more promising trees by reducing competition from other jack pine seedlings (Eyre and LeBarron 1944).

Impact of Deer and Other Mammals

Jack pine seedlings and saplings can be damaged or destroyed by deer browsing. Even at low deer population density, deer browsing causes deformation and retarded growth in jack pine (Steingraber 1989) and sometimes kills trees up to ten years old (Benzie 1977b). Jack pine appears to be a highly preferred conifer species in Itasca State Park, where Orke (1966) found that most browsing on jack pine was severe and impacted upon seedling survival. Although jack pine seedlings were scarce in his study area, all of them had been browsed, about 2/3 of them heavily.

Jack pine is browsed more heavily than other pines during the fall of the year, whereas red and white pine are more heavily browsed during the winter (Aldous 1939). This difference is probably due to accessibility. In the winter, deer are largely restricted to coniferous swamps and rarely use the higher ground where jack pine tend to be located.

Snowshoe hares also damage and destroy jack pine seedlings and saplings by girdling the young trees (Benzie 1977b). Dense seedling and sapling stands provide good cover for hares and are especially vulnerable to damage when hare populations are high. Porcupines sometimes cause serious damage to older trees by stripping the soft bark near the tree tops.

Small rodents feed on jack pine seeds. Deer mice subsist primarily on seeds and consume large amounts of coniferous seed, so they can present a major problem for direct or natural seeding efforts. Ahlgren (1966) found that a litter of laboratory raised deer mice that were fed only jack pine seed consumed an average of 3,078 sound seeds per mouse in seven days. Red-backed voles subsist on a more varied diet of vegetation, fruit and seeds.

Impact of Insects and Diseases

Jack pine budworm damage can result when the shelterwood system of management is used in jack pine stands (Benzie 1973b). In two-story stands, the larvae can fall from the overstory to the young growth below where they defoliate and kill the seedlings. Jack pine can also be damaged by *Cronartium cerebrum* (a gall rust) which causes globose swellings, and *C. comptoniae* (sweet fern rust) which causes stem cankers.

Fire Effects

Fire can easily kill an established jack pine stand. Therefore, although fire is important to natural jack pine regeneration, it can be a negative factor if it occurs in an immature stand. Fire can cause a setback in reproduction which may be undesirable depending upon the future plans for the stand. Young stands are more susceptible to crown fires than mature stands, so fire should be excluded from young stands unless a setback in regeneration and growth can be afforded (Rouse 1986a).

Fire may not necessarily result in loss of the stand or a complete setback, however. Burgess and Methven (1977) observed that 17 year old jack pine in Chalk River, Ontario was able to survive a fire of variable low to moderate intensity and provide adequate regeneration for a partial new age class.

STAND MANAGEMENT

Jack pine often reproduces in very dense stands which, if not thinned, can become stagnant. These overstocked and stagnant stands develop weak and spindly trees (Benzie 1977b) that are susceptible to sleet, ice and wet snowstorms. An over-dense stand in the Superior National Forest that was experimentally thinned provides a good example of this susceptibility (Roe and Stoeckeler 1950). A heavy, wet snow, 5 years after thinning, caused major damage in the form of flattened trees in the unthinned stands, but the thinned stands suffered little damage. Thinning should be accomplished by age 5 or earlier. On plots where thinning was delayed until the stand was 10 years of age, 1 year prior to the snowfall, damage was even greater than on the unthinned plots. Thinning also seemed to decrease snowshoe hare damage. Hares prefer tender bark of small trees and protective cover, both of which were reduced considerably by the thinning process.

Recommended rotation ages for jack pine will depend on the anticipated use of the resource, site quality and the health and vigor of the stand, but will not generally be over 70 years, at which point most stands become decadent (Benzie 1977b). Commercial rotation ages are between 40-70 years, when mature trees are 8-12 inches d.b.h. and 50-80 feet tall (Benzie 1977b).

ASPEN

Aspen is a versatile tree species, in that it reproduces both by seed and vegetative sprouting. It is adapted to reproduce by suckering after fire, but can also do so after clearcutting. Aspen is capable of invading cut-over and burned forest lands in the Lake States by seed, because the seeds are tiny and can travel for miles in air currents (Shirley 1941). However, regeneration by seed requires an open, moist seedbed. Since fires rarely produce moist seedbeds, regeneration by seed does not usually occur after fire (Rouse 1986b). Aspen can successfully invade pine or other forests after fires only thin the stand and can hold the land it has invaded even if subjected to fires at intervals as short as three years. Aspen trees may persist in pine stands for up to 150 years and will regenerate by suckering if the pine stand is destroyed by fire or logging (Graham et al. 1963).

In the Boundary Waters Canoe Area, a network of aspen rhizomes has built up over centuries of fires. Aspen plays a significant role in that area now and is a major threat to red pine survival (Ahlgren 1976). Balsam fir is the most common conifer associated with aspen in Michigan. Over time, it is expected that, without disturbance, balsam fir will be replaced by more tolerant species, such as maple or hemlock. However, with fire disturbance, aspen suckers will sprout from roots of surviving trees and the stands will be regenerated to aspen (Graham, et al. 1963).

Aspen occurs on nearly every soil type, but grows best on deep, well-drained soils (Perala 1977). Hansen and Kurmis (1972) observed that aspen has little dominance on dry, nutrient poor sites in north-central Minnesota and is almost absent from the richest sites. Aspen growth varies with soil moisture and is best on loams with a clayey subsoil and moderately high water table. Optimum depth to ground water is about 33 inches (Heinselman and Zasada 1955). Light loam or loamy sand underlain by clay, with a somewhat deeper water table, is a medium aspen site, while sand underlain by clay, with a low water table is a poor aspen site.

Aspen growth is also affected by shade and the presence of competing vegetation (Alban 1991). On sites examined by Stoeckeler and Macon (1956), competition with established brush or reproduction of other tree species caused failure of aspen sucker stands. Sprouting was better on clearcut sites, where no more than 16.5 square feet of basal area per acre was left intact. On average, height growth in theopen was 3.4 times as fast as in heavily shaded areas. Cutting during the winter produced more numerous and vigorous suckers than did stands cut in summer. Perala (1977) reports similar results about aspen sucker growth and recommends complete clearcutting at rotation age to regenerate pure, fully stocked aspen sucker stands. As little as 10-15 square feet basal area of residual overstory will slow sucker growth by 35-40%.

According to Shirley (1941), an aspen seedling can attain a height of 12 inches or more and develop a strong taproot 8-10 inches long within one year, if free from competing vegetation. Graham et al. (1963) report that aspen growth from seed in a natural stand is 6 inches in year 1, 12-18 inches in year 2 and 3-4 inches in year 3, and from suckers growth is 4-8 inches in year 1 and 12-15 inches by year 3.

Fire is detrimental to aspen stands and should be excluded except for regeneration purposes. Light burning can stimulate the numbers and rate of growth of aspen suckers during the first growing season, but no further advantage is observed during the second season (Shirley 1932b and Stoeckeler 1948). Fall burning in Minnesota has been noted by Rouse (1986b) to stimulate aspen suckering due to increased soil temperatures. Severe fires may kill the aerial portions of an aspen tree, but leave the roots intact and capable of sprouting new trees (Rouse 1986b). Repeated burning in an established aspen stand has been observed to reduce site index by 17 feet or more. Fire is responsible for reducing growth, causing scars that open the way for decay, reducing stocking and volume, site retrogression and early break-up of the stand (Stoeckeler 1948).

Aspen stands are comparatively short-lived under natural circumstances. In the lower peninsula of Michigan, aspen stands may begin to deteriorate anytime after 35 years as the canopy is opened to sunlight (Graham et al. 1963). A variety of factors can lead to the deterioration, including defoliation by insects, wind breakage, ice damage or mechanical thinning.

Growing aspens in combination with conifers is a forest management technique that can lead to a more continuous supply of aspen that will be safer from insects and fungi (Graham et al. 1963). It can be used in areas where the aspen and conifers are being managed for wood production and will eventually be cleared. To maintain this combination successfully, some large conifers must be reserved as seed trees and aspen must be periodically thinned to allow for the survival of an understory of young conifers. The aspen may need to be cleared 2 or 3 times to release the understory conifers before the conifers are even ready for their first cut.

CONVERSION OF ASPEN STANDS TO CONIFERS

Aspen stands are not favorable sites for conifer establishment and survival. Competition for light, crown space and soil moisture/nutrients leads to growth retardation and eventually death of the conifer seedlings, while the aspen thrives (Shirley 1941). In addition, the seedbed is not favorable for conifer seedlings because aspens are rarely uprooted by wind to expose mineral soil. Aspens usually break off above ground, rather than uprooting.

Selection of an appropriate site is the first step to a successful conversion process. Shirley (1941) recommends areas of good soil, where aspen is less than 12 feet high and is not dense, and areas severely burned and supporting only scattered aspen seedlings. Sites where aspen fails to reach pulpwood size before becoming decadent are also good candidates for conversion. Perala (1977) points out that conifers are usually more productive than aspen on poorer sites, so he recommends considering such sites for conversion.

Burning stimulates the production and height growth of aspen suckers, but repeated burning is detrimental to aspen (Ahlgren and Ahlgren 1960). So, if used properly, fire may be useful in the conversion process. Repeated spring prescribed burns have been useful in clearing areas dominated by aspens and in reducing the abundance and vigor of root suckers (Buckman 1965). Standing aspen must be killed in the first fire or otherwise removed to prevent future suckering that would result when the trees were killed in a subsequent fire. Two to three burns, spread 2-3 years apart to allow for build-up of fuel, produce an area free of debris and aspen competition.

Perala (1974) found repeated burning to be an impractical tool for converting aspen stands to conifers except possibly on sandy soils if burning is conducted during the growing season. Fire weather in the Lake States is capricious, and most associated hardwoods and shrubs vigorously maintain themselves. Perala (1977) recommends the following combination of cutting, mechanical and chemical site preparation in lieu of burning. "Aspen stands to be converted to conifers should first be harvested of all usable material. Prepare the site mechanically by shearing, roller chopping or barrel scarifying, or treating chemically between July 15 and August 15 with picloram plus 2,4-D (0.5 pounds + 2 pounds per acre) in 10-20 gallons of water per acre. Plant suitable conifers the following spring.

Release conifers from aspen suckers as needed using 2,4-D or a 50% mixture with 2,4,5-T when oak or other hardwoods are present. Use total rates of 3 pounds per acre in 4-5 gallons of water mixture for aerial spraying; 3 pounds per acre in 10-20 gallons for ground spraying. White spruce and red pine are safe to release after July 1, but release is best after July 15. Jackpine is not safe to release until August 1. Complete the release operations by August 15. Where chemicals cannot be used, hand release during the growing season (June, July, early August) to lessen regrowth of aspen."

HAZEL

Hazel is recognized as a deterrent to pine regeneration because of its shading effect and aggressive growth (Buckman 1964b). The invasion of hazel into pine stands has led to the conversion of considerable acreage to grass and upland brush communities (Brown and Hansen 1955). Hazel invasion has been identified as one of the factors in the lack of pine regeneration in Itasca State Park. In a study of the impact of deer browsing and hazel competition on white pine seedlings, Steingraber (1989) noted that only those seedlings that were planted inside a deer exclosure and unshaded by hazel exhibited positive growth on average.

Hazel is capable of reproducing vegetatively from underground stems, and stands are maintained by continual recruitment of new stems. Vegetative clones are initiated when seedlings are about 10 years old (Tappeiner 1971). A study of hazel populations in undisturbed forests of Minnesota revealed that "once established, dense hazel populations persist and thrive beneath undisturbed aspen-birch and red pine and/or jack pine stands, although densities can shift widely during a 1-year period. During succession, hazel populations will decline as more shade tolerant species enter the tree canopy. Persistent hazel populations have an all-aged structure with frequencies highest in shorter (younger) stems. Decreases in hazel populations seem to result chiefly from reduced natality and (or) high mortality in the short height (young) classes" (Kurmis and Sucoff 1989). Hazel populations were found to exist at lower densities and lower frequencies, have slower height growth and fewer tall stems when growing under fir-spruce and maple-basswood types than when browing under aspen-birch, red pine and/or jack pine stands.

A comparison of hazel growth both inside and outside deer and rabbit exclosures in Itasca State Park revealed that there was no effect of deer and rabbit browsing on hazel growth (Hansen and Bakuzis 1952). There was no significant difference in stem numbers or height between the two site types. Steingraber (1989) also studied the impact of deer browsing on hazel, on a site where both white pine and hazel were growing within and outside of an exclosure. The author observed that both hazel and white pine were browsed, but there was a lack of stunting and lateral branch formation by hazel in response to browsing. White pine was quickly stunted, however, and this provided hazel with a competitive advantage over white pine at high levels of deer browsing. In conclusion the author states that "hazel productivity is indirectly stimulated by the decrease in competitive fitness of white pine seedlings which are severely damaged by browsing and cannot attain vertical height".

Brush invasion appears to be a relatively slow process in its initial stages (Brown and Hansen 1955). Once established, however, the rate of increase in density can be very rapid. Therefore, early recognition of the beginning of invasion is an important step in controlling the invasion, regardless of the control method used. Tappeiner (1971) suggests the following methods for controlling the spread or preventing the establishment of a dense hazel undergrowth: 1) prescribed fire during the seedling stage or before large underground stems and clones are formed, and 2) light herbicide treatment of seedlings and young clones. A moderately hot fire every 10-15 years might be sufficient to control hazel invasion according to Tappeiner (1971) because underground stems are not formed until seedlings are at least 7 years old, and 15 year old clones have only small underground stems.

Buckman (1964b) compared the effectiveness of spring and summer prescribed burns in eliminating hazel. Vigorous and abundant resprouting followed spring burns; whereas, resprouting was less vigorous after summer burns. Repeated summer fires destroyed the ability of hazel to resprout by exposing and killing underground stems and depleting food reserves. Van Wagner (1965) found similar results in prescribed burning experiments on a red and white pine stand with an understory of hazel.

The use of herbicides such as 2,4-D and 2,4,5-T has been successful in releasing red pine from brush competition. Spraying should be done soon after pine leader growth is complete and the terminal bud set is set, around mid-July but before August (Benzie 1977a). The herbicide 2,4-D was also used successfully in a white pine regeneration plot in Itasca State Park to control brush (unknown 1952). One-time spraying did not eliminate the brush completely, so repeated treatments were necessary throughout the period of pine seedling establishment.

Cutting brush by hand requires much labor and regrowth may necessitate several cuttings at 2-3 year intervals (Benzie 1977a). Therefore, this is not considered to be a practical method of removing brush competition.

FIRE

IMPORTANCE OF FIRE TO CONIFEROUS REGENERATION

Fire was viewed as a hazard to forest preservation in the past, which led to a policy of fire suppression for many decades in national parks and forests. But, the policy of fire suppression has a detrimental effect on many species of wildlife, reducing vegetative, faunal diversity and carrying capacity (Agee 1974). The major impact of fire suppression on soil is the increase in the nutrient reservoir of the forest floor. As the forest floor mass increases, nutrients within the organic matter are unavailable for plants. Fires have been suppressed in Itasca State Park, as well, since the 1930's. But, fire was an important factor in maintaining presettlement pine forests in Itasca State Park (Frissell 1973). Historical records show that prior to 1922, fire occurred on average every 8.8 years in Itasca State Park, with any specific location affected by fire approximately every 22 years. Anfang (1972a) reported that, from 1650-1699, the average interval between fires was 16.7 years, and between 1900-1922, when the land was cleared and logged, fires occurred every 3.1 years.

Early stages of conifer growth are believed to be favored on burned land, primarily because seedbed conditions are improved (Ahlgren and Ahlgren 1960). Removal of the forest floor by burning favors the survival of conifer seedlings over the deciduous species. In pine seedlings, the initial root system is only about one inch long; whereas, the fleshy cotyledons of hardwoods permit development of a 5-6 inch root system before the first leaves begin to function. This allows the roots of the hardwoods to penetrate unburned, deep litter to mineral soil before the leaves have an increased water demand. Since the roots of pines are shallow, they can reach mineral soil before drying out only if the litter has been at least partially removed.

Fire also helps to remove or control competing vegetation that would otherwise compromise the establishment of conifer seedlings. One of the major obstacles to pine regeneration in Itasca State Park has been reported by several sources to be brush and shrub competition, such as from hazel. In dense stands of ponderosa pines, controlled fire has further been demonstrated to be an effective thinning tool to eliminate excessive competition and stagnation among the pines themselves (Weaver 1947). A creeping, surface fire was most successful in thinning stands of sapling to small-pole sized pines, where the majority of the suppressed and intermediate trees were eliminated, leaving the majority of the dominants and co-dominants.

EFFECT OF FIRE ON SOIL AND VEGETATION

Fire can affect nutrient cycling and physical characteristics of soil within a community. Romme and Despain (1989) found that nutrients, such as nitrogen, phosphorous and calcium, which are usually tied up in organic matter, are released when organic matter burns. Bacteria, fungi and other microorganisms in the soil increase their rates of nutrient uptake in response to the increase of free nutrients. Ahlgren and Ahlgren (1960) report that coniferous charcoal in soil increases the total nitrogen, but doesn't seem to affect the amount of available nitrogen.

Burning also affects the temperature of soil for sometime after fire because insulating vegetation has been removed, light absorption is increased on the blackened surface and charcoal is present in the soils (Ahlgren and Ahlgren 1960). This change in soil temperature has been found to stimulate growth of aspen suckers. Fire usually decreases soil acidity, but the change may vary with depth and type of soil. The change in acidity is believed to be caused by the presence of ash and by the resultant release of soluble mineral salts, especially those containing calcium. Subsequent leaching of these salts, from the top layers, results in eventual return to the original acidity. The quality of the soil, type and amount of ash are important in determining the extent to which fire affects acidity (Ahlgren and Ahlgren 1960).

Erosion, surface run-off and the possibility of floods are potential risks associated with fire. Fire can also kill or damage trees and shrubs. Fire damage can occur as crown scorch, cambial damage or root damage (Ryan 1982). Crown scorch is determined primarily by flame length, which is determined primarily by how rapidly fine fuels are ignited. Cambial damage is determined primarily by the duration of burning in woody fuels. Resistance to cambial damage increases with tree diameter because of increasing bark thickness. Root damage is determined primarily by the amount of duff that is consumed.

Certain tree and shrub species are capable of vegetative reproduction and may be difficult to eradicate with one fire. If only the aerial portions of the tree are destroyed, suckering may occur from the roots. Rowe (1981) has found that deep burning of the organic layer can nearly eliminate the vegetative reproduction of hazel, alder, willow and the *Ericaceae*. Ahlgren (1960) reports that high soil moisture may be involved in the destruction of underground parts of some vegetatively reproduced species. Soil moisture tends to condense in the upper soil stratum and functions as a thermo-insulator during fire, protecting lower levels from high temperatures. But, this moisture forms steam in the uppermost layer of organic soil during intense fires, which can damage the living tissue more than the dry heat that would occur on drier sites. Seed reproduced species were found mostly on severely burned, moist areas where vegetative sprouting did not compete and seedbed conditions were favorable.

FIRE AS A MANAGEMENT TOOL

While fire is now recognized as an important factor in maintaining the pine forest, allowing all natural fires to run in Itasca State Park is viewed as impractical (Wald 1970). More area might be burned than would be desirable at one time, and it might be hard to stop wildfires short of developed areas or existing stands of timber. Also, since natural fires occur sporadically, it would be difficult to obtain desirable effects in the places and at the times they are needed. Some control of fire is important to pine regeneration in Itasca State Park because successful regeneration does not occur after all fires. Pine regeneration is contingent on several environmental and biotic criteria, including fire intensity, presence of seed supply, climatic conditions prevailing during the years following germination and length of time between fires (Frissell 1973).

Controlled burning would permit careful selection of the area to be burned, so as to obtain the optimum advantage and insure the least disturbance to surrounding timber stands (Wald 1970). Prescribed burning allows the most control over fire (Agee 1974). Allowing some natural fires to burn will create irregularly shaped vegetation mosaics that vary as a function of fuel types and fuel moisture. Uncontrolled burning may deteriorate sites rather quickly, changing the structure and distribution of the vegetative mosaic and reducing desirable habitat. The organic mantle covering the soil may be substantially reduced and soil physical properties may be affected.

During the period of fire suppression in our national parks and forests, fuels were allowed to accumulate to dangerous levels (Wakimoto 1984). A similar situation is likely to have occurred in Itasca State Park. These uniformly high fuel loads can encourage very widespread, intense fires. Fire suppression allows the understory vegetation to become dense and create a fuel ladder from the accumulations on the forest floor to the canopy of overstory trees. This distribution of energy increases the potential for a crown fire to occur (Agee 1974). Several prescribed fires in moist seasons of successive years can decrease fuel loads that have built up to excessive levels during fire suppression. Prescribed fires can then be used during drier times of the year to simulate natural fires.

One of the first steps in reintroducing fire is to assess the quality of the fuels to determine how rapidly a fire will spread. Wakimoto (1984) provides the following expectations from various fuel types. Fuel complexes made up of small diameter branches, fine needles and dead herbaceous understory plants may easily ignite, allow rapid fire spread and respond quickly to short-term weather changes. Fuel complexes made up of large decaying logs may be difficult to ignite and sustain only slow rates of fire spread. Once ignited, they may be extinguished only by the coming of winter snow. Severe forest fires occur where small and large diameter fuels are found in combination. Forest stands with vertically continuous fuels are likely to sustain high intensity crown fires once a surface fire begins.

The relationship between the exposure time and temperature necessary to cause death of plant tissues is exponential. Therefore, small changes in temperature can have a drastic effect on tissue mortality. Ryan (1982) recommends that consumption of large fuels be minimized during prescribed fire to avoid the risk of tissue death. To accomplish this, he recommends either removing the large fuels or burning when they are too wet to burn.

Several weather factors are key variables in selecting appropriate days to conduct prescribed or controlled burns. According to Sando (1969) those factors include air temperature, relative humidity, wind direction, windspeed and precipitation. The criteria for an acceptable burning day in northern Minnesota are: 1) fine fuel spread index between 15-35; 2) windspeed between 5-15 m.p.h.; 3) relative humidity less than 70%; 4) no snow on the ground and 5) less than a trace of rain (.01 inch). Based on these criteria, 25-40 burning days can be expected to occur each year, and the best months for prescribed burning have been found to be July, August and October.

Ohmann and Grigal (1981) found that fire intensity differed with the season of burning in northeastern Minnesota. A spring burn was less intense and destructive, allowing more reproduction by vegetative propagation, as well as seeds. Summer burns removed the forest floor down to the mineral soil and favored seedling establishment by newly dispersed seed. Severe summer burns killed most vegetative structures and many dormant seeds. This allowed for establishment of fall seeding species, such as birch and the conifers.

DEER

Numerous studies have been conducted in an attempt to assess the impact of deer browsing on various vegetation types, acceptable deer densities for certain regions and the success of deer management techniques. There is little doubt that white-tailed deer have an impact on plant species composition, distribution and survival in the areas they browse, especially in parks and nature reserves where deer density can become artificially high (Miller et al. 1992, Porter 1991).

IMPACT OF BROWSING

Tierson et al. (1966) determined, through the use of exclosures, that deer browsing was a limiting factor in the height growth of many hardwood tree species and woody shrubs in the Adirondack Mountains. Deer browsing in northwestern Pennsylvania and northeastern Wisconsin was found to have a serious impact on hardwood regeneration and tree species diversity by Tilghman (1989) and Anderson and Loucks (1979), respectively. In Itasca State Park, Ross et al. (1970) and Steingraber (1989) found that deer browsing caused significant damage to pine seedlings and saplings, thus suppressing regeneration potential.

Strole and Anderson (1992) observed that deer browsing may impact vegetation in a number of ways. It may cause increases in low use species of the forest understory, which may directly reduce recruitment and survival of some tree species. Deer browsing may also reduce plant species diversity, possibly leading to local extinctions of browse species. Selective browsing may cause shifts in tree species composition of the forest understory.

Deer browsing on seedlings may result in reduced seasonal height growth, loss of needle tissue and thus reduced food production and the ability of the seedling to recover from other stresses or to survive and grow, torn rootlets and damage due to trampling (DeYoe et al. 1985). Vigorous seedlings may survive browsing, but will appear bushy due to repeated loss of laterals and leaders. Seedlings under stress are not likely to survive repeated browsing. In a recent (ca.

1989) study of white pine plantations in the Chippewa and Superior National Forests, Mielke et al. (unknown) found most to be in poor to fair condition due to repeated deer browsing and, in some, to blister rust.

A good illustration of the problems associated with high deer density exists in the Northern Highland State Forest of Wisconsin and an adjacent Indian Reservation forest. DeBoer (1947) documented that on the reservation forest, 92% of hemlock and white pine remained unbrowsed, while just outside the reservation on the state forest, hemlock reproduction between one and eight feet in height was virtually nonexistent. Deer densities differed drastically between the two sites because on the reservation unlimited deer hunting was allowed year round, and on the state forest, hunting was restricted. The conclusion was drawn that the difference in deer density was the cause of the difference in coniferous regeneration on the two sites.

DEER BEHAVIOR AND HABITAT NEEDS

DeYoe et al. (1985) provide the following information about black-tailed and mule deer in the Pacific Northwest. This information may or may not be directly applicable to white-tailed deer in Itasca State Park. Deer require cover (hiding and thermal), forage and food for survival. The thermal cover needs differ between the winter and summer seasons. In the winter, deer bed down in areas of high stem density and overstory canopy closure to avoid loss of body het. Cover of this type is provided by dense, second-growth stands and by mature stands with heavy understory vegetation, such as evergreen brush or advanced conifer regeneration that is at least 6 feet above the forest floor. In the summer, deer bed down in cool, moist sites with good air circulation to avoid heat build-up. Cover of this type is provided by mature timber stands with maximum canopy closure and sparse understory vegetation. Graham (1954) points out that low branching coniferous growth provides ideal shelter for deer, but that a pine plantation ceases to provide shelter between 20-30 years of age.

DeYoe et al. (1985) also report that deer feed in forest openings that have been created by timber harvesting or natural disturbances and use nearby stands for cover. Preferred forage for deer includes grasses, forbs and young shoots of woody shrubs. However, availability of these forage types is limited during the fall and winter. Deer feed on conifer seedlings during this period and during spring bud burst when the food quality of coniferous seedlings is high. Deer will also browse on coniferous vegetation during the summer if alternative sources of browse are unavailable. On the Apostle Islands of Michigan, deer were found to utilize deciduous browse independently of the kind of coniferous browse present (Beals et al. 1960). The deer still ate a fair proportion of deciduous browse even under conditions where there was an abundance of highly preferred yew.

Kohn and Mooty (1971) documented that, in north central Minnesota, deer used habitat types including upland deciduous, upland conifer, upland mixed, open fields and cutover lands. Use of different habitat types varied with the time of day, age of the stands, and season of the year. For example, upland deciduous types and disturbed areas were most intensively used during the morning and evening (for feeding), and upland conifer and disturbed areas were used during midday (for bedding). Deer spent most of their time in disturbed areas and young deciduous stands. Use of upland forest types was inversely proportional to the ages of the stands. Deer utilized the small plants and ignored older plants of the same species where both were available, browsing primarily on leaves and current year growth of plants less than three feet tall.

In a study by Nudds (1980) deer foraging behavior was found to be best described as constrained optimization. The author found that when resource levels are high, deer are selective foragers and a nutrient mix is optimized. However, when resource levels are low, deer are generalists, with a focus on meeting energy needs. During the winter, the author found that deer are habitat specialists, seeking out sheltered, coniferous, energy-conserving areas, but are diet generalists, exhibiting foraging behavior that maximizes energy conservation. All food types seem to be of equal value during the winter. Strole and Anderson (1992) found some evidence of a generalist foraging strategy, but noted that both preference and abundance of a species are important in determining how often it is browsed.

A deer movement study in the Adirondacks (Tierson et al. 1985) revealed that both male and female deer maintained striking fidelity to home ranges, in terms of range size, configuration and location from year to year. There was less fidelity to winter ranges, but the same winter yard was used each year, with deer moving through suitable winter range enroute to their home ranges. There was no evidence of territorialism between social groups, but there appeared to be a discrete home range for each group. Verme (1973) documented a strong homing instinct in Michigan deer to return to the same yard each winter, even when physically moved to an unfamiliar location.

A combination of recent small burns and adjacent maturing forest make a very productive habitat complex for deer (Benedict 1989), because they tend to feed near the edges of the forest openings and have cover readily available. However, deer do not utilize forage more than 75 yards from cover, so they are not well-adapted to occupying areas of recent large burns. Graham et al. (1963) found a similar browsing pattern in Michigan after logging. On sites where less than 40 acres were cut, browsing was even over the area. But, where the size of the cut was greater than 40 acres, browsing was heavier along edges than in the center, probably due to distance from cover.

Habitat characteristics seem to affect the distance deer roam in Michigan based on the availability of the habitat to satisfy year-round food and cover requirements (Verme 1973). Deer were observed to have a shorter cruising radius in areas where needed habitat types were better interspersed than in areas consisting of large expanses of single habitat types. In the Adirondacks, winter logging affected deer movements to and the location of their winter range (Tierson et al. 1985). Deer on winter range were observed using adjacent hardwood and hardwood-conifer stands that were being logged, and remained on those areas all winter. Several deer remained on their summer range during winter because of autumn-winter logging on or adjacent to their normal summer range. Shifts or changes in the location of summer home range from summer or autumn logging were not observed.

DENSITY / CARRYING CAPACITY

Artificially high numbers of deer in Itasca State Park have caused problems for pine regeneration, because the browsing has stunted and destroyed young pine seedlings. As part of a management program to maintain a combination of deer and pine regeneration, the carrying capacity of the area must be determined and methods developed to keep deer densities within an acceptable range. Deer populations are expected to increase subsequent to treatment of an area to stimulate pine regeneration due to increased food supply and appropriate habitat (Moritz 1976). Therefore, the author asserts that a pine restoration plan should include increased hunting to minimize browsing early on that would harm pine regeneration. Deer density was found to increase on an area that had been burned in a wildfire by comparison to a similar, but unburned, tract of forest (Vogl and Beck 1970). This finding suggested, therefore, that a burned, mixed forest of resprouting oaks, shrubs and prairie plants such as that found on the post-fire tract provided more preferrable habitat for deer than the unburned forest.

According to simulation models (Cooperrider and Behrend 1983), in a mixed-hardwood forest supportable deer densities were higher in areas where current logging was taking place, due to the browse production in the cutover areas and the increase in available winter forage in the form of slash. It was determined that a density of 3 deer per square mile was sufficient to prevent adequate regeneration after 20 years on a cutover area with a residual basal area of 60 square feet per acre. Adequate regeneration was anticipated only if deer populations were kept below 0.5 deer per square mile for 10-20 years. Heavier cutting was expected to decrease the time for stems to grow out of reach of deer, thus decreasing the period of time that deer densities would have to be kept so low. Furthermore, the quality and duration of availability of herbaceous forage on late-spring and summer range were found to be crucial in determining the density of deer that could be supported by an area.

Graham et al. (1963) offered the following method for estimating deer density in Michigan aspen stands. If there is no obvious browsing, there are less than 15 deer per square mile. If there is light, but no serious damage, there are 15-20 deer per square mile. If browsing damage is light, except in local spots, there are 20-25 deer per square mile. If browsing damage is conspicuous, there are 25-35 deer per square mile. If browsing is generally heavy to destructive, there are 35-50 deer per square mile. If all palatable woody stems are browsed, there are at least 50 deer per square mile. If browsing is destructive to all palatable species, there are more than 50 deer per square mile.

Deer carrying capacities have been reported for various regions and various habitat types throughout the north central and northeastern United States. For example, Tilghman (1989) determined from an enclosure study in northwestern Pennsylvania that the overall carrying capacity of the hardwood forests of the region was 15 deer per 259 hectares. In the Adirondacks, high deer densities (approximately 27 per square mile) were blamed for the lack of hemlock regeneration. After hunting reduced the deer numbers to an average of 12 per square mile, changes were noted in vegetative growth and reproduction suggesting that the deer populations were approaching supportable numbers.

In northern Wisconsin, major differences in deer abundance appear to be based on forest composition, with high numbers of deer located in forests that were predominantly aspen, oak and jack pine of fire origin (McCaffery 1986). Maximum carrying capacity appeared to vary from 15 deer per square mile in poorer habitat areas to 45 deer per square mile in the best areas. Availability of conifer cover did not correlate well with the differences in carrying capacity, but the amount of aspen, oak and non-stocked forests did. As northern hardwoods and balsam fir increased, non-stocked land closed in, and aspen acreage was lost to natural succession and forced conversion to pine, carrying capacity was expected to decline. According to McCaffery (1986), a model to predict carrying capacity shows that unbroken pole-sized northern hardwoods have a carrying capacity of about 6 deer per square mile, hardwood timber with 10% grassy openings might have a carrying capacity of 20 deer per square mile and, even without grassy openings, the carrying capacity might be 40 deer per square mile if 80% of the habitat is aspen, oak, jack pine and clearcut stands less than 10 years old.

Alverson et al. (1988) found that in the hemlock-hardwood forests of northern Wisconsin, presettlement forest conditions, including severe winters and wide expanses of virgin timber lacking undergrowth, produced marginal habitat for white-tailed deer. Therefore, deer populations were probably maintained at 2-4 deer per square kilometer of range (deer/sq km x 2.6 = deer/sq mi). In recent years, deer numbers have been much higher, between 5-12 deer per square kilometer. But, the authors claim that the forests of northern Wisconsin have been unable to support deer densities of 8 per square kilometer or higher while still maintaining healthy reproduction of deer sensitive plant species. They recommend maintaining deer numbers at presettlement densities. Anderson and Loucks (1979) also note high deer densities in the forests of northern Wisconsin, and cite them as the cause of the failure of hemlock reproduction. However, they estimate much higher densities than Alverson et al. (1988), ranging from 37-110 per square kilometer.

Anfang (1972a) reported that census counts from 1935-1945 revealed that there were about 75 deer per section in Itasca State Park, but that the area could only support about 16 deer per section successfully. Feeney (1935) estimated the deer carrying capacity of Itasca State Park to be one deer per 40-50 acres. Kohn and Mooty (1971) estimated average deer densities in north central Minnesota to range between 16-22 deer per square mile, based on pellet studies, but did not indicate whether or not these numbers were supportable. In the Superior National Forest, drive censuses in 1939 indicated that deer averaged 12.2 per square mile (Fredine 1940). Deer numbers had been declining since 1937, with an average loss of 11 deer per square mile of wintering range due to malnutrition. This finding suggested that the average of 12.2 deer per square mile exceeded the carrying capacity of the area.

CONTROL MEASURES

Because deer browsing has such a negative impact on pine reproduction, certain measures are necessary to control deer numbers during the vulnerable years of early growth. Pine trees from about 0.15 to 2.1 meters (6 inches to 7 feet) are susceptible to deer browsing in winter (Ross et al. 1970) and should be protected from browsing. Wilson (1946) recommended that young pines in Itasca State Park be protected from deer browsing for a minimum of 20 years in order to improve the likelihood of survival to maturity.

Tierson et al. (1966) found that deer were a limiting factor in the height growth of hardwood species and woody shrubs in the Adirondack Mountains due to browse pressure. The authors found that all-aged selection methods, in which the reproduction process occurs continuously throughout the rotation of the stand, is likely to have little success in areas where deer are abundant. They recommend using even-aged methods in such areas to reduce and make manageable the period during which deer control measures will be necessary.

The method of controlling deer damage may take the form of reducing deer numbers, excluding deer from vulnerable areas, or discouraging browsing by placing a physical or chemical barrier between individual trees or tree parts and the deer.

REDUCING DEER NUMBERS

Methods of controlling deer numbers include predation, sport hunting and population reduction by wildlife managers. Predation by wolves, coyotes, etc. is expected to at best exert a dampening effect on a deer population, but is not expected to have much influence on reducing population size (Kroll et al. 1986). Hunting has received mixed reviews in terms of its effectiveness in controlling deer numbers.

Kroll et al. (1986) claim that public hunting rarely achieves population reduction goals because harvest rates rarely approach recruitment rates, which are usually about 30-40%. Hunter access is often a major physical constraint to harvest. Because hunters tend to remain close to roads and trails, hunting pressure is unevenly distributed over large areas, producing patchy, often locally dense, deer populations. Heavy hunting pressure during the early part of an antlerless season may cause shifts in activity patterns and home ranges. Therefore, a system involving rotation of hunting areas and times may be necessary in order to meet harvest quotas. De Yoe et al. (1985) also claim that regulating deer numbers by hunting is not very effective. They point out that to stabilize an area's deer population, 33% of the herd must be killed. To accomplish this, does and fawns must be killed, which is highly controversial.

Public hunting, by permit only, was used successfully under controlled conditions in the Adirondack Mountains to reduce deer numbers, but it took two years to accomplish the reduction goals (Behrend et al. 1970). When deer numbers were large and the animals were unwary, it took about 59 hours to bag one deer. As deer density decreased, approximately 100 hours were required. Some immigration occurred from surrounding areas subsequent to the reduction in deer numbers, but there was not an immediate influx of deer to replenish the herd. Since the net effect of immigration could not completely replenish greatly reduced deer herds in one year, the authors concluded that deer number could be reduced substantially by heavy hunting and maintained at reduced levels by lighter hunting. Deer harvests of the magnitude necessary for control require effective hunting pressure, which is possible only where large numbers of hunters are provided adequate access. Some type of trail or road system would have to be maintained in order to provide access in areas where logging is not practiced.

Because deer were found to maintain high fidelity to their summer range in the Adirondacks, Tierson et al. (1985) recommended that control of deer damage be aimed at the population doing the damage. To do so, deer hunting permits should be allocated based on area hunted rather than deer range availability. Graham et al. (1963) recommend that, to secure larger kills, hunting parties be directed to problem areas by publications, advertising and personal contacts, good camp locations be made available near deer concentrations, shooting stands be established, drives organized and roads maintained into areas where hunting should be encouraged.

EXCLUDING DEER FROM VULNERABLE AREAS

Electric fencing has been used successfully to exclude deer from fields containing various crops, fruit trees and young coniferous trees. However, construction and maintenance costs can be high, especially in rough terrain (DeYoe et al. 1985). Deer usually penetrate fencing by going under or through it, rather than jumping over. Palmer et al. (1985) observed that after experiencing an initial shock from an electric fence, deer stayed approximately 1 meter away from the wires and didn't try to jump over it, despite the food available on the other side. A 2-3 meter open strip should be left outside the perimeter of an electric fence to ensure that deer will approach the fence walking rather than jumping. That way they will experience a shock and learn to avoid the area. Palmer et al. (1985) recommend the Penn State Vertical Deer Fence, which is described in their paper.

The International Paper Company in Coudersport, PA, has also had success in protecting hardwood clearcuts from overbrowsing by deer by installing an electric fence (Kochel and Brenneman unk.). They used a 5 strand vertical fence, 58 inches high, with the bottom strand of wire 10 inches off the ground and 12 inch spacing between each additional wire. The fence was not deer proof, but did curtail deer penetration enough so that the clearcuts were regenerating successfully. The most effective fence was found to be one that is located outside the cut area, has few holes or low areas and is kept running at about 4000 volts, with energizer pulses at or above 40 per minute. Electric fencing was recommended over chemical repellents, individual seedling protection and other techniques to reduce browsing, because these methods had either been ineffective or too costly to implement.

Deer do not walk through felled tops and other logging debris, so seedlings might be protected by such debris (Graham et al. 1963). Deer may be prevented from entering a vulnerable area by surrounding the area with an unbroken windrow of slash and logging debris, wide enough to discourage jumping. Deer are hesitant to wander more than 150-200 feet from protective cover, so browse damage may be reduced in the interior of a clearcut, if the area cut is large enough (greater than 100 acres) (DeYoe et al. 1985).

Deer learn to associate the sound of a power saw or a tractor with food and are attracted by the noises of cutting operations (Graham et al. 1963). These sounds can be used to coax deer out of aspen sucker stands where they are overbrowsing. This is a conditioned response and develops most quickly under conditions where food is scarce.

PHYSICAL OR CHEMICAL BARRIERS

Physical barriers are available in a wide range of materials and labor costs and can be used to protect individual trees or portions of trees. They differ from fencing in that they do not exclude wildlife from important feeding habitat. DeYoe et al. (1985) offer considerable information after having evaluated the effectiveness of a number of physical barriers. For example, they found that Vexar tubes prevent browse damage effectively, have no adverse effect on seedling survival, can enhance terminal growth and they are effective for multipest control (deer, mountain beaver, mice and elk). Vexar leader tubes are also effective in preventing browse damage to terminals, have no adverse effect on seedlings survival and can enhance height growth. But, restriction and bending of the terminals can be a problem, especially on small seedlings unable to remain fully erect under the weight of the tube. Flexible netting has proven effective in preventing browse damage and has no adverse effect on seedling survival. However, if applied improperly, the incidence of bent terminal leaders increases. Paper budcaps, stapled around the terminal leader and bud, form a protective cylinder, but normally require annual adjustment or replacement. Reemay sleeves are very effective in preventing browse damage and, if used properly, have no adverse effect on seedling survival. However, on hot, dry sites, particularly those with south-southwest aspects, Reemay sleeves may have an adverse affect on seedling survival. This is due to the inability of seedlings, whose branches are tightly bunched up and experiencing poor air circulation, to dissipate heat fast enough to prevent tissue damage. Similar problems have also been observed with netting and, to a lesser degree, Vexar tubes on hot, dry sites. Injury can be minimized by using Reemay sleeves that are larger in diameter and lighter weight in material.

DeYoe et al. (1985) also examined the effectiveness of chemical repellents. They found that repellents had mixed success. The most effective was putrified egg solids, which is available in three formulations called Big Game Repellent, Deer-Away in liquid form and Deer-Away in dry form. They caution, however, that chemical repellents should not be applied to young or physiologically stressed seedlings.

LITERATURE CITED

Agee, J. K. 1974. Environmental impacts from fire management alternatives. National Park Service Western Regional Office Report.

Ahlgren, C. E. 1959a. Vegetational development following burning in the northern coniferous forest of Minnesota, pp. 21-22. Proceedings, Society of American Foresters.

Ahlgren, C. E. 1959b. Some effects of fire on forest reproduction in northeastern Minnesota. Journal of Forestry 57:194-200.

Ahlgren, C. E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. Ecology 41:431-445.

Ahlgren, C. E. 1966. Small mammals and reforestation following prescribed burning. Journal of Forestry 64:614-618.

Ahlgren, C. E. 1970. Some effects of prescribed burning on jack pine reproduction in northeastern Minnesota. Miscellaneous Report 94, Forestry Series 5-1970, University of Minnesota Agricultural Experiment Station.

Ahlgren, C. E. 1974. Effects of fires on temperate forests: north central United States, pp. 195-223. Fire and Ecosystems, Academic Press, New York.

Ahlgren, C. E. 1976. Regeneration of red pine and white pine following wildfire and logging in northeastern Minnesota. Journal of Forestry 74:135-140.

Ahlgren, C. E. 1979. Buried seed in the forest floor of the Boundary Waters Canoe Area. Minnesota Forestry Research Note 271. University of Minnesota, School of Forestry.

Ahlgren, I. F. and C. E. Ahlgren. 1960. Ecological effects of forest fires. Botanical Review 26:483-533.

Alban, D. H. 1974. Red pine site index in Minnesota as related to soil and foliar nutrients. Forest Science 20:261-269.

Alban, D. H., D. A Perala, M. F. Jurgensen, M. E. Ostry, and J. R. Probst. 1991. Aspen ecosystem properties in the Upper Great Lakes. US Dept. Agriculture, Forest Service, N. Central Forest Exper. Sta., St. Paul, Mn. Research Paper NC-300.

Aldous, S. E. 1939. Pine in the diet of white-tailed deer. Journal of Forestry 37:265-267.

Alm, A. A. and R. Schantz-Hansen. 1970. Planting pine tubelings in Minnesota. Journal of Forestry 68:353-357.

Alverson, W. S., D. M. Waller and S. L. Solheim. 1988. Forests too deer: edge effects in northern Wisconsin. Conservation Biology 2:348-358.

Anderson, R. C. and O. L. Loucks. 1979. White-tail deer (*Odocoileus virginianus*) influence on structure and composition of *Tsuga canadensis* forests. Journal of Applied Ecology 16:855-861.

Anderson, R. L. 1973. A summary of white pine blister rust research in the Lake States. General Technical Report NC-6. USDA Forest Service .

Anfang, R. A. 1972a. The Itasca State Park Forestry Demonstration Area. Unpublished Master's Paper, College of Forestry, University of Minnesota, St. Paul, MN.

Anfang, R. A. 1972b. Feeding habits of porcupine (*Erethizon dorsatum L.*) in Itasca State Park, Minnesota. Student Major Report. College of Forestry, University of Minnesota, 47 pp.

Bakuzis, E. V. 1954. Some observations on natural reproduction in a mixed red pine-balsam fir stand in Itasca State Park, Minnesota. Unpublished Paper, 50 pp.

Bakuzis, E. V. Year Unk.?

Beals, E. W., G. Cottam and R. J. Vogl. 1960. Influence of deer on vegetation of the Apostle Islands, Wisconsin. Journal of Wildlife Management 24:68-80.

Behrend, D. F., G. F. Mattfeld, W. C. Tierson and J. E. Wiley, III. 1970. Deer density control for comprehensive forest management. Journal of Forestry 68:695-700.

Benedict, J. 1989. Wildland fire management plan Voyageurs National Park. National Park Service Document.

Benzie, J. W. 1968. Regeneration of cutover jack pine stands. Research Note NC-49. US Forest Service, North Central Forest Experiment Station.

Benzie, J. W. 1973a. Red pine, pp. 58-60. Agriculture Handbook 445. US Department of Agriculture, Forest Service.

Benzie, J. W. 1973b. Jack pine, pp. 60-61. Agriculture Handbook 445. US Department of Agriculture, Forest Service.

Benzie, J. W. 1977a. Manager's handbook for red pine in the north central states. General Technical Report NC-33. US Forest Service, North Central Forest Experiment Station.

Benzie, J. W. 1977b. Manager's handbook for jack pine in the north central states. General Technical Report NC-32. US Forest Service, North Central Forest Experiment Station.

Bergeron, Y. and M. Dubuc. 1989. Succession in the southern part of the Canadian boreal forest. Vegetatio 79:51-63.

Bergman, H.F. 1924. The composition of climax plant formations in Minnesota. Papers Michigan Academy of Science 3:51-60.

Bergman, H.F. and H. Stallard. 1916. The development of climax formations in northern Minnesota. Minnesota Botanical Studies 4:333-378.

Blowers, R. K. 1960. An analysis of selected red pine stands in Itasca State Park, MN. Minnesota Academy of Science Proceedings 28:6-9.

Brown, R. T. 1967. Influence of naturally occurring compounds on germination and growth of jack pine. Ecology 48:542-546.

Brown, B. A. and H. L. Hansen. 1955. Preliminary analysis of factors related to upland-brush density in Minnesota pine stands. Minnesota Forestry Note 35, University of Minnesota, School of Forestry.

Buckman, R. E. 1953. Regeneration of pine in Itasca State Park. Student Major Report, School of Forestry, University of Minnesota, 41 pp.

Buckman, R. E. 1964a. Silvicultural use of prescribed burning in the lake states. Proceedings, Society of American Foresters. (see B. Thoma Vol. 2, pg. 103-105)?

Buckman, R. E. 1964b. Effects of prescribed burning on hazel in Minnesota. Ecology 45:626-629.

Buckman, R. E. 1965. Repeated spring prescribed burning reduces abundance and vigor of aspen root suckering. Journal of Forestry 63:23-24.

Buell, M. F. and W. A. Niering. 1957. Fir-spruce-birch forests in northern Minnesota. Ecology 38:602-610.

Burgess, D. M. and I. R. Methven. 1977. The historical interaction of fire, logging and pine: a case study at Chalk River, Ontario. Source: see B. Thoma Vol. 3, pg. 133-152?

Cayford, J. H. 1971. The role of fire in the ecology and silviculture of jack pine. 10th Annual Tall Timbers Fire Ecology Conference 10:221-244.

Cayford, J. H. and D. J. McRae. 1983. The ecological role of fire in jack pine forests, pp. 183-189. The Role of Fire in Northern Circumpolar Ecosystems. John Wiley & Sons, Ltd.

Cheo, K. 1946. Ecological changes due to thinning red pine. Journal of Forestry 44:369-371.

Cheyney, E. G. Year Unk. A working plan for Itasca State Park. Unpublished Paper.

Cheyney, E. G. 1942. American silvics and silviculture. University of Minnesota Press, Minneapolis, 472 pp.

Cheyney, E. G. 1947. The future of Itasca State Park. The Conservation Volunteer 10:41-44.

Chrosciewicz, Z. 1974. Evaluation of fire-produced seedbeds for jack pine regeneration in central Ontario. Canadian Journal of Forest Research 4:455-457.

Clark, J. S. 1990. Fire and climate change during the last 750 yr. in northwestern Minnesota. Ecological Monographs 60:135-159.

Cooley, J. H. 1972. Site preparation for jack pine on Grayling sands. Research Note NC-138. US Forest Service, North Central Forest Experiment Station.

Cooperrider, A. Y. and D. F. Behrend. 1983. Simulated experiments with a model of deer populations and northern forest vegetation, pp. 313-321. *In* Analysis of Ecological Systems: State-of-the-Art in Ecological Modelling. W. K. Lauenroth, G. V. Skogerboe and M. Flug (editors). Elsevier Scientific Publishing Company.

Corson, C. W., J. H. Allison and E. G. Cheyney. 1929. Factors controlling forest types on the Cloquet Forest, Minnesota. Ecology 10:112-125.

DeBoer, S. G. 1947. The deer damage to forest reproduction survey. Wisconsin Conservation Bulletin 12:1-23.

DeYoe, D. R., D. S. DeCalesta and W. Schaap. 1985. Understanding and controlling deer damage in young plantations. Extension Circular 1201. Oregon State University Extension Service.

Engle, L. G. 1951. Releasing white pine from oak and aspen. Technical Note 346. US Forest Service, Lake States Forest Experiment Station.

Eyre, F. H. 1933. Aspen competition in Norway pine plantations. Journal of Forestry 31:318-321.

Eyre, F. H. 1938. Can jack pine be regenerated without fire? Journal of Forestry 36:1067-1072.

Eyre, F. H. and R. K. LeBarron. 1944. Management of jack pine stands in the Lake States. Technical Bulletin 863. US Department of Agriculture.

Feeney, W. S. 1935. Special report on deer at Itasca. US Department of Interior, National Park Service Records.

Feeney, W. S., et al. (unspecified). Itasca State Park, White-tailed Deer Reports. Compilation of official correspondence between National Park Service and Minnesota Department of Conservation, between November 9, 1934 and February 12, 1937.

Fowells, H. A. 1965a. Red pine, pp. 432-446. Silvics of Forest Trees of the United States, Agricultural Handbook 271. USDA Forest Service.

Fowells, H. A. 1965b. Eastern white pine, pp. 329-337. Silvics of Forest Trees of the United States, Agricultural Handbook 271. USDA Forest Service.

Fredine, G. 1940. Deer inventory studies in Minnesota. The Minnesota Academy of Science Proceedings 8:42-49.

Frelich, L. E. 1986. Natural disturbance frequencies in the hemlock-hardwood forests of the Upper Great Lakes Region. Ph.D. thesis, University of Wisconsin, Madison.

Frelich, L. E. 1992. The relationship of natural disturbances to white pine stand development, pp. 27-37. *In* White Pine Symposium Proceedings. Stein, R. A. and M. J. Baughman (Editors), University of Minnesota Extension Service, St. Paul, MN.

French, D. W. 1992. White pine blister rust can be controlled. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Frissell, Jr., S. S. 1973. The importance of fire as a natural ecological factor in Itasca State Park, MN. Quaternary Research 3:397-407.

Geerinck, P. A., W. A. Getchell and G. L. Chapman. 1954. Response to release of underplanted white and red pine. Technical Note 29. University of Maine Forestry Department.

Graham, S. A. 1954. Changes in northern Michigan forests from browsing by deer. Transactions of the 19th North American Wildlife Conference 19:526-533.

Graham, S. A., R. P. Harrison, Jr., and C. E. Westell, Jr. 1963. Aspens. University of Michigan Press, Ann Arbor, Michigan. 272 pp.

Grant, M. L. 1929. The burn succession in Itasca County, Minnesota. M.A. thesis. University of Minnesota.

Grant, M. L. 1934. The climax forest community in Itasca County, Minnesota, and its bearing upon the successional status of the pine community. Ecology 15:243-257.

Gysel, L. W. 1966. Ecology of a red pine (*Pinus resinosa*) plantation in Michigan. Ecology 47:465-472.

Hansen, H. L. 1956. White pine regeneration during an eight year period following chemical brush release. Minnesota Forestry Notes 51. University of Minnesota School of Forestry.

Hansen, H. L. 1967. Ecological and silvicultural research on forest recreational areas. Minnesota Science 23:42-43.

Hansen, H. L. and E. V. Bakuzis. 1952. Effects of deer and rabbits on hazel brush at Itasca State Park. Minnesota Forestry Note 10, University of Minnesota, School of Forestry.

Hansen, H. L., and R. M. Brown. 1950. Deer, brush and the Itasca Park Forest. The Conservation Volunteer 13:1-5.

Hansen, H. L. and D. P. Duncan. 1954. The management of the Itasca State Park Forest to meet recreational objectives, p. 123-125. Proceedings, Society of American Foresters.

Hansen, H. L. and R. R. Johnson. 1957. Some effects of Monuron on eastern white pine (*Pinus strobus*) regeneration. Minnesota Forestry Note 59. University of Minnesota School of Forestry.

Hansen, H. L. and V. Kurmis. 1972. Natural succession in north-central Minnesota, pp. 59-66. *In* Aspen:Symposium Proceedings, General Technical Report NC-1. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, 154 p.

Hansen, H. L., V. Kurmis and D. D. Ness. 1974. The ecology of upland forest communities and implications for management in Itasca State Park, Minnesota. University of Minnesota Agricultural Experimentation Technical Document.

Heckman, S. T. 1992. White pine management on the Menominee and its evolutionary process, pp. 157-167. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Heiberg, S. O. and D. P. White. 1950. Potassium deficiency of reforested pine and spruce stands in northern New York. Soil Science Society of America Proceedings 15:369-376.

Heinselman, M. L. 1954. The extent of natural conversion to other species in the Lake States aspen-birch type. Journal of Forestry 52:737-738.

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research 3:329-382.

Heinselman, M. 1981. Fire and succession in the conifer forests of northern North America. Pp 374-405 In West, D. C., H. H. Shugart and D. B. Botkin (editors). Forest succession. Springer-Verlag, NY.

Heinselman, M. L. 1983. Fire regimes and management options in ecosystems with large high-intensity fires, pp. 101-109. *In* Proceedings of Symposium and Workshop on Wilderness Fire. Technical Report INT-182. US Forest Service.

Heinselman, M. L. and Z. A. Zasada. 1955. A review of literature relating to quaking aspen sites. Station Paper 32:1-61. US Department of Agriculture, Lake States Forest Experiment Station.

Hendee, J. C., G. H. Stankey and R. C. Lucas. 1978. Fire in wilderness ecosystems, pp. 249-278. *In* Wilderness Management. Miscellaneous Publication #1365. USDA Forest Service.

Henry, D. G. 1968. Some ecological trends in an old growth red pine stand in Itasca State Park, Minnesota. Unpublished Paper, School of Forestry, University of Minnesota, St. Paul, MN.

Hibbs, D. E. 1982. White pine in the transition hardwood forest. Canadian Journal of Botany 60:2046-2053.

Jacobson, G. L., Jr. 1979. The palaeoecology of white pine (*Pinus strobus*) in Minnesota. Journal of Ecology 67:697-726.

Jaakko Pöyry Consulting, Inc. 1992. Silvicultural systems. A background paper for a generic environmental impact statement on timber harvesting and forest management in Minnesota. Tarrytown, NY: Jaakko Pöyry Consulting, Inc.

Johnson, E. A. 1992. Fire and vegetation dynamics: studies from the North American boreal forest. Cambridge Studies in Ecology. Cambridge University Press, England.

Jones, A. C. 1992a. White pine: evaluation of site conditions related to blister rust hazard, p. 197. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Jones, A. C. 1992b. The problem with pine, pp. 64-72. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Kayll, A. J. 1968. Heat tolerance of tree seedlings. Proceedings of the Annual Tall Timbers Fire Ecology Conference 8:89-105.

Kell, L. L. 1938. The effect of the moisture-retaining capacity of soils on forest succession in Itasca State Park, Minnesota. The American Midland Naturalist, Vol. unknown.

Kochel, J. and R. Brenneman. Date Unknown. Use and effectiveness of electric fencing in protecting clearcuts from deer browsing. International Paper Company, Coudersport, Pennsylvania.

Kohn, B. E. and J. J. Mooty. 1971. Summer habitat of white-tailed deer in north-central Minnesota. Journal of Wildlife Management 35:476-487.

Kotar, J. 1992. Managing white pine: finding the proper niche, pp. 150-156. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Kroll, J. C., W. D. Goodrum and P. J. Behrman. 1986. Twenty-seven years of overbrowsing: implications to white-tailed deer management on wilderness areas. Wilderness and Natural Areas in the Eastern United States: A Management Challenge, D. L. Kulhavy and R. N. Conner (Editors). Center for Applied Sciences, School of Forestry, Stephen F. Austin University, Nacogdoches, Tx.

Kurmis, V. 1969. Dynamics of advance reproduction in upland forest communities in Itasca State Park, Minnesota. Ph.D. thesis, University of Minnesota.

Kurmis, V. 1985. Changes in upland forest communities in Itasca State Park over a 19-year period. Staff Paper #52. University of Minnesota, School of Forestry.

Kurmis, V. and H. L. Hansen. 1969. Occurrence and distribution of pine reproduction in Itasca State Park, Minnesota. Minnesota Forestry Research Notes 210. University of Minnesota, School of Forestry.

Kurmis, V. and H. L. Hansen. 1972. Pine reproduction in Itasca State Park; analysis of moisture-nutrient coordinates. Journal of the Minnesota Academy of Science; 38:37-41.

Kurmis, V. and E. Sucoff. 1989. Population density and height distribution of *Corylus cornuta* in undisturbed forests of Minnesota: 1965-1984. Canadian Journal of Botany 67:2409-2413.

Landis, S. 1993. Seventh-generation forestry. Harrowsmith Country Life 42:26-33.

LeBarron, R. K. and F. H. Eyre. 1939. The release of seeds from jack pine cones. Journal of Forestry 37:305-309.

LeBarron, R. K., G. Fox and R. H. Blythe, Jr. 1938. The effect of season of planting and other factors on early survival of forest plantations. Journal of Forestry 36:1211-1215.

Lee, S. C. 1924. Factors controlling forest successions at Lake Itasca, Minnesota. The Botanical Gazette 78:129-174.

Little, S., D. E. Beck and L. Della-Bianca. 1973. Eastern white pine. Agriculture Handbook 445. USDA Forest Service.

Locey, C. T. 1992. White pine artificial regeneration system, pp. 168-169. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Logan, K. T. 1966. Growth of tree seedlings as affected by light intensity. Publication 1160. Canadian Department of Forestry.

Maissurow, D. K. 1935. Fire as a necessary factor in the perpetuation of white pine. Journal of Forestry 33:373-378.

Marshall, W. H., T. Schantz-Hansen, and K. E. Winsness. 1955. Effects of simulated overbrowsing on small red and white pine trees. Journal of Forestry 53:420-424.

Maycock, P. F. and J. T. Curtis. 1960. The phytosociology of boreal conifer-hardwood forests of the Great Lakes region. Ecological Monographs 30:1-35.

McAndrews, J. W. 1965. Postglacial history of prairie, savanna and forest in northwestern Minnesota. Memoirs of the Torrey Botanical Club 22:1-72.

McCaffery, K. R. 1986. Deer carrying capacity in northern Wisconsin, pp. 54-69. Transactions of the 22nd Annual Meeting of the Northeast Deer Technical Committee.

McCool, S. F. 1966. Some attitudes toward vegetation management at Itasca State Park. Student Major Report, School of Forestry, University of Minnesota, St. Paul, MN. 23 pp.

McQuilkin, W. E. 1959. Establishing white pine on open land. pp 31-44 In What's known about managing eastern white pine. USDA. Northeastern Forest Experiment Station, Upper Darby, PA. Station Paper 121.

Methven, I. R. 1973. Fire, succession and community structure in a red and white pine stand. Information Report PS-X-43. Petawawa Forest Experiment Station, Chalk River, Ontario.

Mielke, M. E., D. A. Charette, G. Collyard and J. G. O'Brien. Year Unknown. Biological evaluation of white pine plantations on the Chippewa and Superior National Forests. Unpublished document.

Miller, S. G., S. P. Bratton and J. Hadidan. 1992. Impacts of white-tailed deer on endangered and threatened vascular plants. Natural Areas Journal 12:67-74.

Miller, W. E. 1978. Use of prescribed burning in seed production areas to control red pine cone beetle. Environmental Entomology 7:698-702.

Moritz, R. F. 1976. Itasca State Park pine restoration project. Division of Parks and Recreation, Minnesota Department of Natural Resources.

Nicholls, T. H. and R. L. Anderson. 1977. How to identify white pine blister rust and remove cankers. US DA Forest Service, NCFES, St. Paul, 8 pp.

Nudds, T. D. 1980. Forage "preference": theoretical considerations of diet selection by deer. Journal of Wildlife Management 44:735-740.

Ohmann, L. F., C. T. Cushwa and R. E. Lake. 1973. Wilderness ecology: the upland plant communities, woody browse production and small mammals of two adjacent 33 year-old wildfire areas in northeastern Minnesota. General Technical Report NC-7. USDA Forest Service, North Central Forest Experiment Station.

Ohmann, L. F. and D. F. Grigal. 1981. Contrasting vegetation responses following two forest fires in northeastern Minnesota. American Midland Naturalist 106:54-64.

Ohmann, L. F. and R. R. Ream. 1971. Wilderness ecology: virgin plant communities of the Boundary Waters Canoe Area. Research Paper NC-63. US Forest Service, North Central Forest Experiment Station.

Oliver, C. D. 1981. Forest development in North America following major disturbances. Forest Ecology and Management 3:153-168.

Orke, D. N. 1966. Patterns and intensity of white-tailed deer browsing on the woody plants of Itasca State Park. M.S. Major Report, School of Forestry, University of Minnesota, 61 pp.

Palmer, W. L., J. M. Payne, R. G. Wingard and J. L. George. 1985. A practical fence to reduce deer damage. Wildlife Society Bulletin 13:240-245.

Pastor, J. and D. J. Mladinov (sp?). 1991.?

Peet, R. K. 1984. Twenty-six years of change in a *Pinus strobus, Acer saccharum* forest, Lake Itasca, Minnesota. Bulletin of the Torrey Botanical Club 3:61-68.

Perala, D. A. 1974. Repeated prescribed burning in aspen. Research Note NC-171. US Forest Service, North Central Forest Experiment Station.

Perala, D. A. 1977. Manager's handbook for aspen in the north central states. General Technical Report NC-36. USDA Forest Service, North Central Forest Experiment Station.

Perry, G. S. 1935. Effect of fire on seedlings. Forest Leaves 25:7.

Pinto, F. 1992. Silvicultural practices in Ontario's white pine forests, pp. 170-178. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Porter, W. F. 1991. White-tailed deer in eastern ecosystems: implications for management and research in national parks. US Dept. Interior, National Park Service, Denver, CO.

Rajala, J. 1992. Growing white pine for today's markets, pp. 120-122. *In* White Pine Symposium Proceedings, Stein, R. A. and M. J. Baughman (Editors). University of Minnesota, St. Paul.

Reifsnyder, W. E., L. P. Herrington and K. W. Spalt. 1967. Thermophysical properties of bark of shortleaf, longleaf and red pine. Bulletin 70. Yale University School of Forestry.

Robbins, M. K. 1984. How to select planting sites for eastern white pine in the Lake States. Publication NA-FB/M-8, USDA Forest Service.

Roe, E. I. and J. H. Stoeckeler. 1950. Thinning over-dense jack pine seedling stands in the Lake States. Journal of Forestry 48:861-865.

Romme, W. H. and D. G. Despain. 1989. The Yellowstone fires. Scientific American 261(5):37-46.

Ross, B. A., J. R. Bray and W. M. Marshall. 1970. Effects of long-term deer exclusion on a *Pinus resinosa* forest in north-central Minnesota. Ecology 51:1088-1093.

Rouse, C. 1985. Fire protection and use in red pine management. Publication 85-02. Proceedings of the Second Region V Technical Conference, Society of American Foresters.

Rouse, C. 1986a. Fire effects in northeastern forests: jack pine. General Technical Report NC-106. US Department of Agriculture, Forest Service.

Rouse, C. 1986b. Fire effects in northeastern forests: Aspen. General Technical Report NC-102. US Department of Agriculture, Forest Service.

Rouse, C. 1988. Fire effects in northeastern forests: red pine. General Technical Report NC-129. USDA Forest Service, North Central Forest Experiment Station.

Rowe, J. S. 1981. Concepts of fire effects on plant individuals and species. Wein, R. W. and D. A. MacLean (editors), Symposium Proceedings, Fire in Northern Circumpolar Ecosystems, Wiley, NY.

Rudolf, P. O. 1937. Lessons from past forest planting in the Lake States. Journal of Forestry 35:72-76.

Rudolf, P. O. 1939. Why forest plantations fail. Journal of Forestry 37:377-383.

Rudolf, P. O. 1946. Successful jack pine regeneration in lower Michigan. Technical Note 254. US Department of Agriculture, Lakes States Forest Experiment Station.

Rudolf, P. O. 1990. *Pinus resinosa*-red pine, pp. 442-455. *In* USDA Handbook 654, Silvics of North America, Volume 1: Conifers.

Rudolph, T. D. and P. R. Laidly. 1990. *Pinus Banksiana*-jack pine, pp. 280-293. USDA Handbook 654, Silvics of North America, Vol 1:Conifers.

Ryan, K. C. 1982. Evaluating potential tree mortality from prescribed burning. Proceedings of Symposium on Site Preparation and Fuels Management on Steep Terrain, Washington State University, pp. 167-179.

Sando, R. W. 1969. Prescribed burning weather in Minnesota. Research Paper NC-28, USDA Forest Service.

Sanow, R. and B. Barnacle. 1992. Protect conifer tree seedlings from deer browsing with paper bud caps. Minnesota DNR, Div. Forestry, Silviculture Field Tip No. 6, 2pp.

Sauerman, K. H. 1992. Artificially established white pine plantations in Minnesota: a survey. MS Plan B paper, unpublished. University of Minnesota.

Schantz-Hansen, T. 1952. The Cloquet red pine thinning plots. Journal of Forestry 50:480-482.

Shirley, H. L. 1932a. Light intensity in relation to plant growth in a virgin Norway pine forest. Journal of Agricultural Research 44:227-244.

Shirley, H. L. 1932b. Does light burning stimulate aspen suckers? II. Journal of Forestry 30:419-420.

Shirley, H. L. 1933. Improving seedbed conditions in a Norway pine forest. Journal of Forestry 31:322-328.

Shirley, H. L. 1937. Direct seeding in the Lake States. Journal of Foresty 35:379-387.

Shirley, H. L. 1941. Restoring conifers to aspen lands in the Lake States. Technical Bulletin 763. US Department of Agriculture, 37 pp.

Shirley, H. L. 1945. Reproduction of upland conifers in the Lake States as affected by root competition and light. The American Midland Naturalist 33:537-612.

Smith, D. M. 1951. The influence of seedbed conditions on the regeneration of eastern white pine. Bulletin 545. The Connecticut Agricultural Experiment Station, New Haven, Connecticut.

Spaeth, J. N. 1922. Notes on release of white pine in Harvard Forest, Petersham, Massachusetts. Journal of Forestry 20:117-121.

Spurr, S. H. 1954. The forests of Itasca in the nineteenth century as related to fire. Ecology 35:21-35.

Spurr, S. H. and J. H. Allison. 1956. The growth of mature red pine in Minnesota. Journal of Forestry 54:446-451.

Stallard, H. 1929. Secondary succession in the climax forest formations of northern Minnesota. Ecology 10:476-547.

Stearns, F. 1992. Ecological characteristics of white pine, pp. 10-18. *In* White Pine Symposium Proceedings. Stein, R. A. and M. J. Baughman (Editors), University of Minnesota Extension Service, St. Paul, MN.

Steingraber, S. K. 1989. Deer browsing, plant competition and succession in a red pine forest, Itasca State Park, Minnesota. Ph.D. thesis, University of Michigan.

Stewart, D. M. 1957. Factors affecting local control of white pine blister rust in Minnesota. Journal of Forestry 55:832-837.

Stoeckeler, J. H. 1948. The growth of quaking aspen as affected by soil properties and fire. Journal of Forestry 46:727-737.

Stoeckeler, J. H. and W. R. Curtis. 1960. Soil moisture regime in southwestern Wisconsin as affected by aspect and forest type. Journal of Forestry 58:892-896.

Stoeckeler, J. H. and G. A. Limstrom. 1942. Ecological factors influencing reforestation in northern Wisconsin. Ecological Monographs 12:191-212.

Stoeckeler, J. H. and J. W. Macon. 1956. Regeneration of aspen cutover areas in northern Wisconsin. Journal of Forestry 54:13-16.

Stoeckeler, J. H. and A. W. Sump. 1940. Successful direct seeding of northern conifers on shallow water-table areas. Journal of Forestry 38:572-577.

Strole, T. A. and R. C. Anderson. 1992. White-tailed deer browsing: species preferences and implications for central Illinois forests. Natural Areas Journal 12:139-144.

Strothmann, R. O. 1967. The influence of light and moisture on the growth of red pine seedlings in Minnesota. Forest Science 13:182-191.

Sucoff, E. I. and J. H. Allison. 1968. Fire defoliation and survival in a 47-year old red pine plantation. Minnesota Forestry Research Notes 187. University of Minnesota School of Forestry.

Swain, A. M., 1973. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Quarternary Res. 3:383-396.

Swain, A. M. 1980. Landscape patterns and forest history in the Boundary Waters Canoe Area, Minnesota: a pollen study from Hug Lake. Ecology 61:747-754.

Swift, E. 1948. Deer damage to forest reproduction survey. Publication 347. Wisconsin Conservation Department Final Report.

Tappeiner, II., J. C. 1971. Invasion and development of beaked hazel in red pine stands in northern Minnesota. Ecology 52:514-519.

Thomas, P. A. and R. W. Wein. 1985a. The influence of shelter and the hypothetical effect of fire severity on the postfire establishment of conifers from seed. Canadian Journal of Forestry 15:148-155.

Thomas, P. A. and R. W. Wein. 1985b. Delayed emergence of four conifer species on postfire seedbeds in eastern Canada. Canadian Journal of Forest Research 15:727-729.

Tierson, W. C., G. F. Mattfeld, R. W. Sage, Jr. and D. F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management 49:760-769.

Tierson, W. C., E. F. Patric and D. F. Behrend. 1966. Influence of white-tailed deer on the logged northern hardwood forest. Journal of Forestry 64:801-805.

Tilghman, N. G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Management 53:524-532.

Tryon, E. H. 1948. Effect of charcoal on certain physical, chemical and biological properties of forest soils. Ecological Monographs 18:81-115.

Unknown. 1952. Brush control to aid natural regeneration of pine. Itasca State Park Document. See B. Thoma Vol. 4, pt. 9-10.?

Unspecified. 1986. A management plan for Itasca Wilderness Sanctuary Scientific and Natural Area, Appendix: Itasca Wilderness Sanctuary Scientific and Natural Area Resource Inventory. Scientific and Natural Areas Program, Section of Fish and Wildlife, Minnesota Department of Natural Resources.

Van Wagner, C. E. 1965. Prescribed burning experiments: red and white pine. Publication #1020. Canadian Department of Forestry.

Van Wagner, C. E. 1970. Fire and red pine. Proceedings of the Annual Tall Timbers Fire Ecology Conference.

Van Wagner, C. E. and I. R. Methven. 1977. Prescribed fire for site preparation in white and red pine. Proceedings of Symposium on White and Red Pine, Ontario Ministry of Natural Resources and Canadian Forestry Service.

Verme, L. J. 1973. Movements of white-tailed deer in upper Michigan. Journal of Wildlife Management 37:545-552.

Verrall, A. F. 1938. The probable mechanism of the protective action of resin in fire wounds on red pine. Journal of Forestry 36:1231-1233.

Vogl, R. J. and A. M. Beck. 1970. Response of white-tailed deer to a Wisconsin wildfire. American Midland Naturalist 84:270-273.

Wakimoto, R. H. 1984. Current fire management research in Glacier National Park. Western Wildlands, Fall 1984:20-25.

Wald, K. D. 1970. Itasca State Park: some alternate courses of development and management. Student Major Report, School of Forestry, University of Minnesota, 31 pp.

Watson, R. 1937. Jack pine in Michigan. US Forest Service, Region 9. Milwaukee, Wisconsin., 47 p.

Weaver, H. 1947. Fire - nature's thinning agent in Ponderosa pine stands. Journal of Forestry 45:437-444.

Webb, S. L. 1985. Windstorm effects of forest dynamics at Itasca State Park, Minnesota. Itasca Biology Program. See Ben Thoma Volume 1, pg. 43.

Wehr, M. A., J. A. Mattson, R. W. Bofinger and R. L. Sajdak. 1992. Ground-application trial of hexazinone on the Ottawa National Forest. Research Paper NC-308. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, 34 p.

Wendel, G. W. and H. C. Smith. 1990. *Pinus strobus*-eastern white pine, pp. 476-488. *In* USDA Handbook 654, Silvics of North America, Volume 1: Conifers.

Whitney, G. G. 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. Ecology 67:1548-1559.

Willard, E. V. 1936. Management plan of Itasca State Park and Forest. State of Minnesota.?

Wilson, C. S. 1946. Toward better conservation of trees and deer in state parks. The Conservation Volunteer 9:20-27.

Wright, H. E. 1968. The roles of pine and spruce in the forest history of Minnesota and adjacent areas. Ecology 39:938-955.

Wright, H. E., Jr. 1974. Landscape development, forest fires, and wilderness management. Science 186:487-495.

Wright, H. E. Jr. and M. L. Heinselman. 1973. Introduction - the ecological role of fire in natural conifer forests of western and northern North America. Quaternary Research 3:319-328.

Zehngraff, P. J. 1943. Jack pine regeneration following clear cutting on the Chippewa National Forest. Journal of Forestry 41:122-125.